ECONOMIC GEOLOGY

AND THE

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A SEMI-QUARTERLY JOURNAL PUBLISHED BY
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ECONOMIC GEOLOGISTS

VOL. 49 JANUARY–FEBRUARY, 1954 NO. 1

THE ELIZABETH COPPER MINE, VERMONT.[1]

H. E. McKINSTRY AND AIMO K. MIKKOLA.

ABSTRACT.

Since the first discovery of sulphides in 1793, the Vermont Copper Belt has yielded ore containing an aggregate of about 120 million pounds of copper. The orebodies occur in schists of Paleozoic (probably Ordovician) age in the middle-grade zone of metamorphism. In the Elizabeth Mine the main oreshoot, 6,000 feet in pitch length, follows the plunge of an overturned syncline and is localized by a bed of phlogopite-tremolite-carbonate rock along a strong zone of deformation on the straight limb of a fold. Sulphides were introduced later than both the folding and metamorphism of the rock and were emplaced by replacement together with some filling of potential open spaces. The ore consists of massive and disseminated sulphides, chiefly pyrrhotite, with enough chalcopyrite to yield a little under 2 percent copper in the ore as mined. Sparse accessory sulphides are pyrite, sphalerite, molybdenite, and traces of galena, tetrahedrite and tennantite. Where the wall rock is amphibolite, hornblende alters to biotite which, in extreme cases, is changed to sericite. In biotite schist, biotite and plagioclase are sericitized.

No nearby magmatic source is evident but the Copper Belt occupies a peripheral position with respect to the area of great plutons of the New Hampshire Magma Series.

INTRODUCTION.

ASIDE from the minor distinction of being the only operating metal mine in New England, the Elizabeth Mine is of both geological and historical interest. Discovered shortly after the Revolution, it is said to have been the largest copper producer in the United States (10)[2] at certain periods before the development of the Michigan deposits.

The main orebody is a lens of sulphide ore that has been developed for more than 6,000 feet on its gentle northward plunge to a depth 975 feet lower than its outcrop. The overall length throughout which sulphides have been mined or developed is 8,300 feet.

[1] Presented as two papers before the joint meetings of the Society of Economic Geologists and the Geological Society of America: Detroit, November 9, 1951, and Boston, November 13, 1952.

[2] Numbers in parentheses refer to Bibliography at end of paper.

Location.—The Elizabeth Mine is in eastern Vermont, 2 miles southeast of South Strafford, 7 miles west of the Connecticut River and 15 miles northwest of Hanover, N. H. Not counting a few prospects, it is the southernmost mine of the Vermont Copper Belt, an area twenty miles from south to north and two miles wide, which includes 3 mines that have produced copper in the past as well as half a dozen other sulphide occurrences.

History and Production.—Although sulphides were discovered at the site of the open cut of the Elizabeth Mine in 1793 they were worked at first only for making iron sulphate (copperas) and it was not until 1830 that any substantial amount of copper was produced there. Meanwhile, at the Ely Mine, eight miles to the north, copper production had begun in 1821. The Pike Hill Mines, 20 miles north of Elizabeth, date from 1854. Production at all of the mines continued with many interruptions until the drop in prices following World War I; only the Elizabeth has been active at any time since then. Total production of the Copper Belt has probably amounted to roughly 120,000,000 lbs., not all of which can be substantiated statistically for lack of complete records. The following figures, however, are all based on records although for certain years the amount of contained copper has been computed by making plausible assumptions as to the grade of the ore mined.

	Lbs. copper contained in ore mined
Elizabeth Mine	71,750,000
Ely Mine	37,250,000
Pike Hill Mines	9,000,000
	118,000,000

Nearly three-quarters of the recorded production of the Elizabeth Mine has been achieved since its reopening in 1943 by the Vermont Copper Company under the active sponsorship of George Adams Ellis of Bennington, Stanley Wilson, former governor of Vermont, and others.

From 1943 to the end of 1952 this company has produced 1,568,000 tons of ore averaging 1.81% Cu and containing 56,774,781 lbs. of copper [3] of which 51,495,356 lbs. was recovered in concentrate having an average assay of 23.6% Cu. The highest grade of ore for any of these years was 2.56% Cu in 1946. The largest year's production was 260,701 tons of 1.62 percent ore in 1952 from which the recovery in copper concentrates was 91 percent. The present mill is capable of handling 1,000 tons a day. Some pyrrhotite concentrate finds a market as a source of sulphur for the local paper industry.

Previous Publications.—The earliest comprehensive report on the geology of the region was Hitchcock's (5) "Geology of Vermont," which gives considerable historical and operating data regarding the mines but has little to say about the local geology.

Subsequently various rather brief accounts (11) of the geology were published, the most extended one by Smyth and Smith (8). More recently, descriptions and maps of the copper belt have been made by Jacobs and Doll (6) and by White (13) and associates, who also prepared maps and brief de-

[3] These figures include about 1.2 million lbs. contained in 60,000 tons of 1% ore hauled from the Ely dump in 1949–50 for treatment at the Elizabeth mill.

scriptions of the principal mines. A recent publication by the Elizabeth Mine staff (1) contains a brief description of the geology contributed anonymously by one of the present writers.[4]

Regional Geology.—The orebodies of the Copper Belt occur in two rock formations, the Waits River and the overlying Gile Mountain, as shown in Figure 1, the Elizabeth Mine being in Gile Mountain formation. Both formations are of Paleozoic age, probably to be dated somewhere between middle Ordovician and late Devonian. The Waits River is generally considered equivalent to the Tomifobia Formation of Quebec which Clark (14) considers Ordovician.

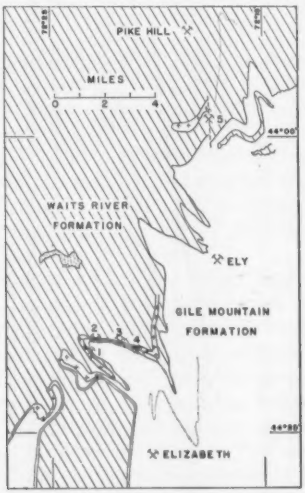


FIG. 1. Vermont Copper Belt, showing location of mines and prospects. 1. Webster. 2. Walker. 3. Gove. 4. Orange. 5. Cookville. Crosses: Standing Pond Amphibolite. Stippled: Granite. (After maps by White, Doll and others.)

Regional Structure.—The structure as indicated by the mapped contact between the two formations (Waits River and Gile Mountain) consists of a series of recumbent zig-zag folds plunging toward the northeast (i.e. *not* southerly as one might expect from the map-pattern). These folds are extraordinary in that the older rocks appear on the insides of structural synclines[5] and the younger rocks in the cores of structural anticlines.

[4] A still more recent description has just appeared (7a).

[5] As the term is used here, a *structural syncline* is a fold whose limbs dip toward each other regardless of the relative ages of the rocks. This is contrasted with a *stratigraphic syncline*, defined as one whose internal portion is occupied by younger rocks regardless of the present attitude of the bedding. Ordinarily a stratigraphic syncline is also a structural syncline but if it has been overturned beyond the recumbent stage it becomes a structural anticline. White and Jahns (14, p. 196) use the term "syncline" without modification, to designate a fold in which the older rocks are on the flanks, i.e. a stratigraphic syncline in the present definition.

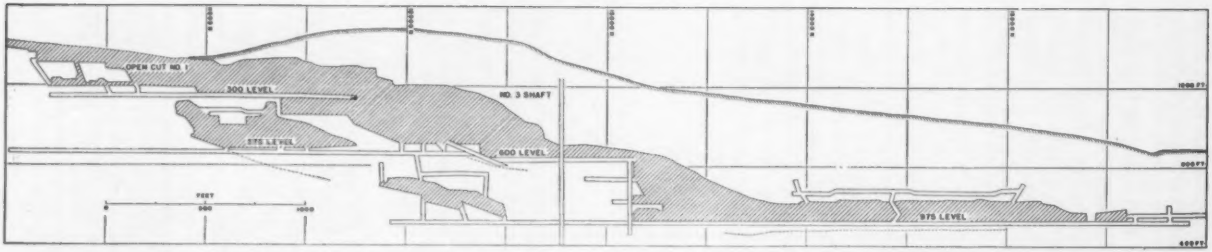


FIG. 2 (upper). Elizabeth Mine. Longitudinal section looking west, showing workings. Cross hatching indicates ground stoped or being stoped.

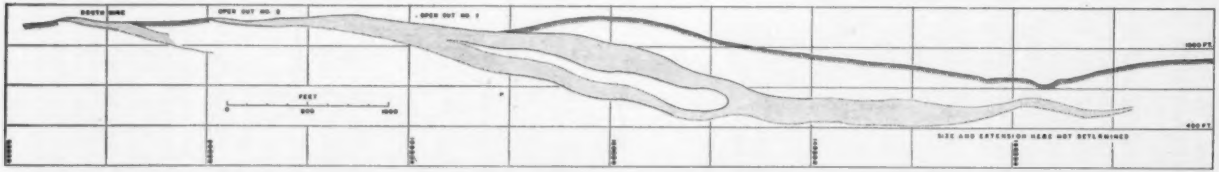


FIG. 3 (lower). Elizabeth and South Mines. Longitudinal section looking west. Generalized outlines of oreshoots (stippled). (Full extent of the oreshoot north of Coord. 16,000 N. is not yet determined.)

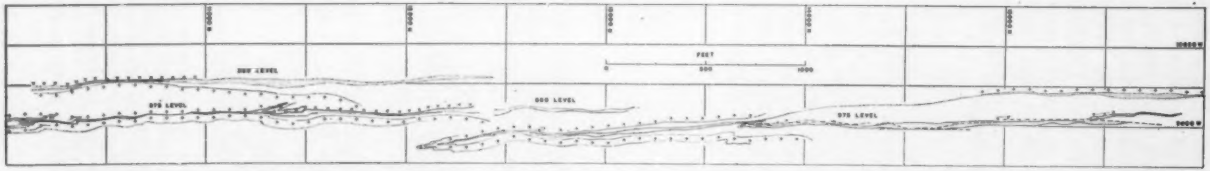


FIG. 4. Composite geologic map of selected levels. (Ore is shown by stippling, Hangingwall and Footwall amphibolite by crosses, Westwall amphibolite by x-pattern.)

Folds of the same type are repeated for 100 miles or more to the south in association with the Strafford, Chester and other domes (9). The origin of these folds is puzzling but authorities seem to agree that uplift of the rocks occupying the central portions of the domes is in some measure responsible.

Position of the Copper Belt.—The cleavage, roughly paralleling the axial planes of these folds, forms, according to White and Jahns (14, p. 210), an arch with gentle northward plunge. The Copper Belt lies 2 to 5 miles east of the axis of this cleavage arch and roughly parallel to it.

No nearby source of mineralizing solutions is recognizable; the nearest exposed plutons are of Barre Granite, extensively quarried 20 miles northwest of the Pike Hill Mines. A small exposure of it occurs 12 miles northwest of the Elizabeth Mine.

Nevertheless the sulphide deposits do stand in broad structural relationship to the granitic rocks of the region. The great areas of Paleozoic granites in New England occupy a broad zone from Maine through Massachusetts and New Hampshire to Connecticut. West of this zone is a narrower zone of smaller and more widely spaced plutons. Belts of sulphide ores, both the Vermont Copper Belt and the pyrite-base metal belt of the Eastern Townships of Quebec, lie in or near this zone of small plutons. Still farther west and northwest is a zone of serpentines and other ultramafics but no more Paleozoic granites.

Zoning of metamorphism reflects in a broad way the distribution of plutonic intrusives and is related to the emplacement of the New Hampshire Magma Series during the Acadian Revolution (middle to late Ordovician) (2).

The high-grade (sillimanite) zone embraces the belt of large granitic bodies. From this region the intensity of metamorphism declines westward to low grade in Western Vermont, the gradation interrupted by a narrow but continuous low-grade belt (biotite and chlorite zones) paralleling the Connecticut River (3, Map, p. 6). The Copper Belt lies in a zone of middle-grade metamorphism within the biotite zone west of the Connecticut Valley. The Elizabeth Mine is in the kyanite zone, although according to Jacobs (7) sillimanite has been found nearby. This long insular strip of middle grade metamorphism conceivably overlies an elongated intrusive body that appears at the surface in small intrusions (Barre granite) of the New Hampshire Magma Series. Alternatively, of course, it may merely reflect deformational features.

GEOLOGY OF THE ELIZABETH MINE.

The Gile Mountain formation, in which the orebodies occur, is composed chiefly of garnet-bearing biotite schist. For the most part it lacks recognizable horizon markers except for a group of beds characterized by high content of hornblende which has served to disclose the local structure, a syncline [6]

[6] Projection of fold axes from White's mapping would indicate that this structural syncline is a stratigraphic anticline in the sense that the older rocks are on the inside of the fold. To avoid complicating the description this probability will be disregarded. "Tops of beds" and "overlying beds" will refer to their present structural positions in folds; not necessarily to their true stratigraphic sequence.

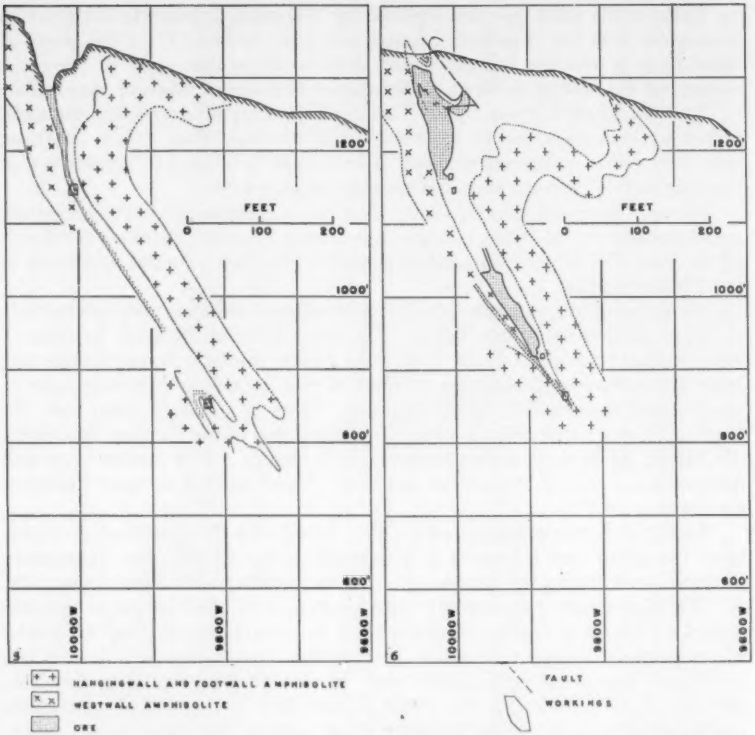


FIG. 5. Cross section at Coord. 10,500 N looking north, and FIG. 6 at 11,000 N.

with its axis overturned so that it dips about 65 degrees eastward (Figs. 5 to 8).

Description of Rocks.

As the ore zone is on an eastward-dipping limb of the syncline, the rocks to the east of it have been designated the Hangingwall Sequence; those to the west of it the Footwall Sequence.

Hangingwall Sequence.—In the hangingwall sequence the generalized succession of beds from east to west is:

1. Garnet-mica schist, the main country rock of the region.
2. Hangingwall amphibolite member.
3. Garnet-mica schist similar to 1.
4. Sericitic schist (probably an alteration phase of 3).
5. Ore zone.

Descriptions of these rocks are from the southern part of the mine, where they are best exposed:

Garnet-mica Schist.—The country rock in the neighborhood of the mine is a relatively coarse-grained schist with pronounced cleavage and commonly with slip-cleavage. Its general uniformity is interrupted by occasional discontinuous quartzite beds and by veinlets and lenticles of quartz and of pegmatitic material, some of which contains bluish crystals of kyanite. Characteristically the schist contains porphyroblastic garnets 4 to 7 mm. in diameter,

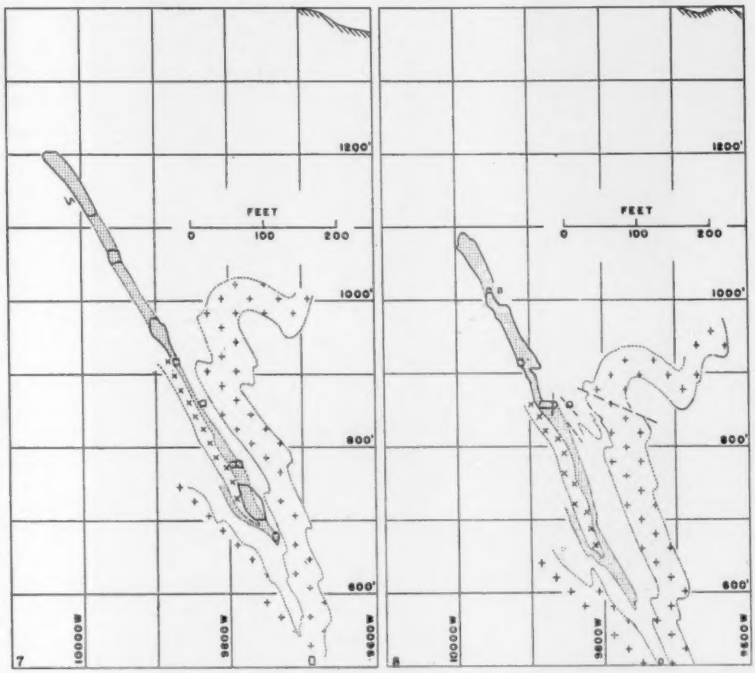
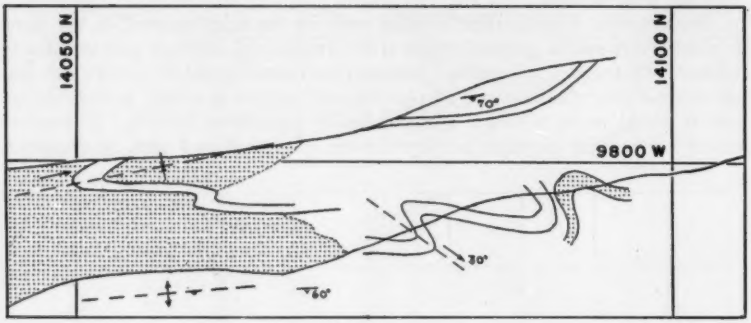


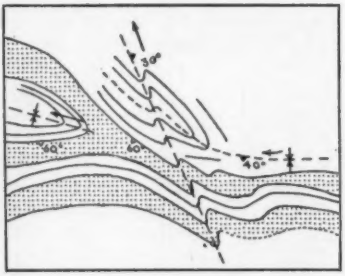
FIG. 7. Cross section at Coord. 12,000 N looking north, and FIG. 8 at 12,500 N.

generally showing helicitic textures resulting from rotation. Besides garnet, the principal constituents of the schist are quartz, biotite, plagioclase (An_{25}), muscovite and carbonate. Accessory minerals are epidote, apatite, sphene, local hornblende, some cordierite and the customary opaque minerals.

Even remote from sulphide bodies there is some evidence of alteration or retrograde metamorphism; margins of biotite flakes are altered to chlorite and garnets have kelyphitic rims.

The schist member (No. 3 above) that overlies the Hangingwall Amphibo-





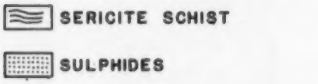


FIG. 9a (upper). Plan of a fold and a cross fold within the ore zone. Drift 975 N.

FIG. 9b (lower). Plan showing axis of early fold deformed by a cross fold. 560 Sublevel at 15,665 N.

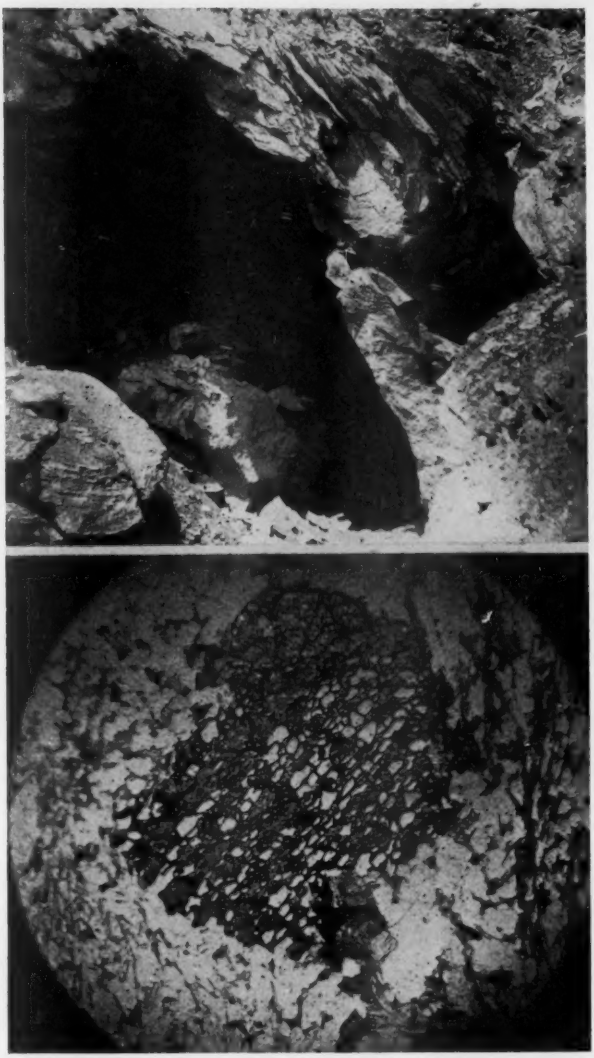
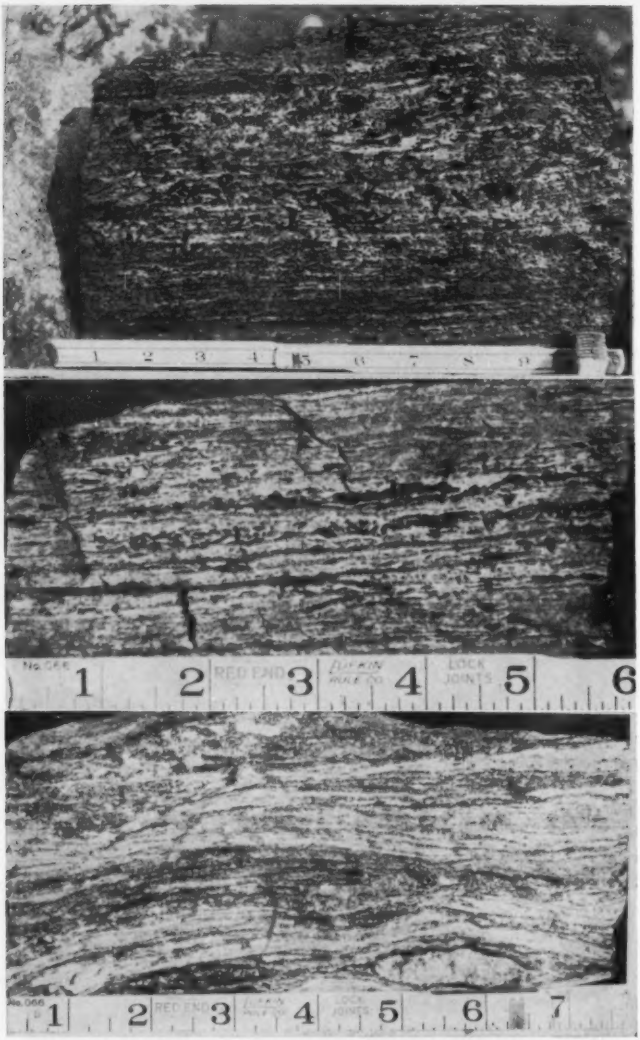


FIG. 10 (upper). Synclinal fold in amphibolite forming overwall of orebody. Open holes stoped ore. (Part of the fold shown by dotted lines in the upper left corner of Fig. 5.) Photo by R. Little.

FIG. 11 (lower). Rotated garnet crystal containing inclusions of quartz. From Hangingwall Amphibolite. Thin section × 18. Photo by Mikkola.



FIGS. 12 TO 14. Stages in alteration of amphibolite. Photos of hand specimens by R. Little.

FIG. 12 (upper). Banded amphibolite.

FIG. 13 (center). Partly silicified amphibolite, 2 feet from sulphides.

FIG. 14 (lower). Completely silicified and biotitized amphibolite, adjoining ore.

lite is similar to No. 1 except that it contains muscovite (in part sericitic), some if not all of which is attributable to hydrothermal alteration associated with the ore deposition.

Hangingwall Amphibolite Member.—The term "amphibolite," though perhaps not strictly applicable, is used locally to designate rocks rich in hornblende. The hornblende, as seen in thin section, is grass green, with the re-

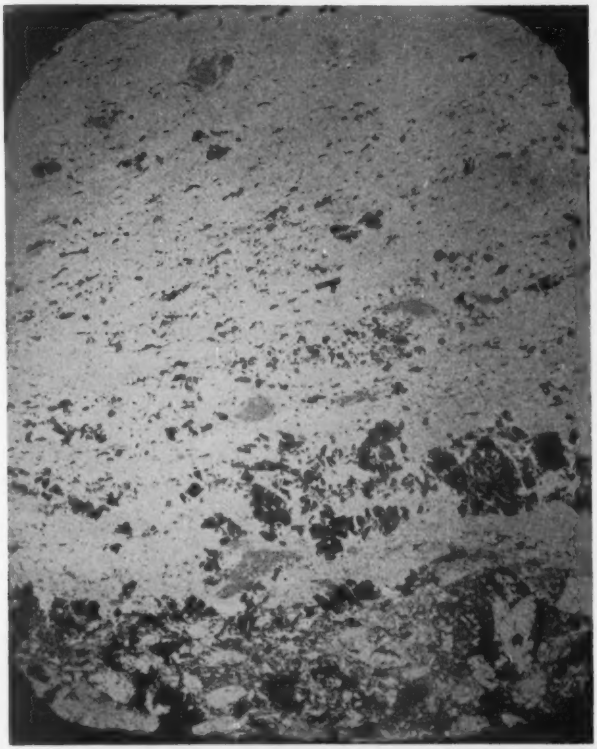


FIG. 15. Sulphides adjacent to a pre-ore fault. Pyrrhotite and chalcopyrite (white); sphalerite (light gray); rock fragments (black). Note banded arrangement of dark inclusions and increase in size (downward) away from fault plane. Polished section × 5. Photo by A. R. Smith.

fractive indices of common hornblende. The other main constituents of the rock are brownish red almandite garnet, plagioclase (An_{25}), carbonate, black biotite, and locally epidote.

Occurrence of these minerals in varying proportions in individual bands or beds has permitted subdivision of the Hangingwall Amphibolite into 5 sub-

members constituting in the main an alternation of garnet-free amphibolite with garnet-bearing amphibolite but including near the bottom one bed which is rich in biotite and contains interbedded layers of quartzite dotted with very small garnets. In most of the amphibolite bands the hornblende occurs as radiating groups of prisms up to 15 cm. long; locally they are altered to rosettes of biotite (Fig. 16). In the "slightly banded amphibolite" which is made up of 5 to 10 mm laminae of quartz and hornblende-biotite, large hornblende prisms cut across the lamination. In some of the garnet-bearing bands the garnets are conspicuously large, ranging up to 15 mm in diameter, and are commonly more or less rotated (Fig. 11).

The texture in bands rich in biotite is schistose, but in the more massive amphibolite bands it is gneissic. Some beds are so coarse grained and fresh-looking as to resemble igneous rock although they are unquestionably products of metamorphism and recrystallization.

Origin of the Amphibolite.—The amphibolite at the Elizabeth Mine is similar to the Standing Pond Amphibolite, which borders the Waits River formation around the Strafford Dome, a mile to the west. Because of the presence of feldspar fragments, the Standing Pond has been regarded as a metamorphosed crystal tuff (3). In the low grade zone it is a greenstone schist (3). In the rock at the Elizabeth Mine the bedded nature and particularly the interlamination with quartzitic bands suggest similar derivation from a bedded tuff. Derivation from sedimentary carbonate beds is conceivable but seems less likely.

Ore Zone.—The ore zone is marked by a band of tremolite-phlogopite schist ("skarn"), bordered on the east by the garnet-biotite schist of the Hangingwall Sequence and on the west by amphibolite of the Footwall Sequence, from which it is separated in places by a band of mica schist. The tremolite-phlogopite schist with its abundance of brown mica bears some resemblance to altered amphibolite which, indeed, it may be, but the absence of remnants of hornblende and the mineralogical composition of the rock suggest derivation from a sedimentary carbonate member. In fact, in places the tremolite rock is adjoined by calcite-biotite schist that might properly be described as impure marble. Of possible significance here is the recognition by White and Billings (12) of quartzitic marble in the Gile Mountain Formation at about this stratigraphic horizon, 20 miles to the north, where the rocks are in the staurolite zone of metamorphism.

Whatever its origin, the consistent character and continuity of the tremolite-phlogopite member suggest that it is a distinct stratigraphic unit. Its characteristic mineral is reddish-brown mica in books about 5 mm in diameter constituting 30 to 40 percent of the rock. Accompanying the phlogopite is pale green tremolite in radiating fibrous textures, partly altered to talc. At the southern end of the ore deposit the same rock contains abundant euhedral 3 to 5 mm porphyroblasts of plagioclase with well-developed albite twinning.[7]

[7] This plagioclase-bearing facies, mapped by White and associates as porphyritic biotite schist, is probably what Smyth and Smith (8, p. 677) described as a dike of medium grained granite that "lies on one or the other of the walls of the orebody" and is "in places completely changed into ore."

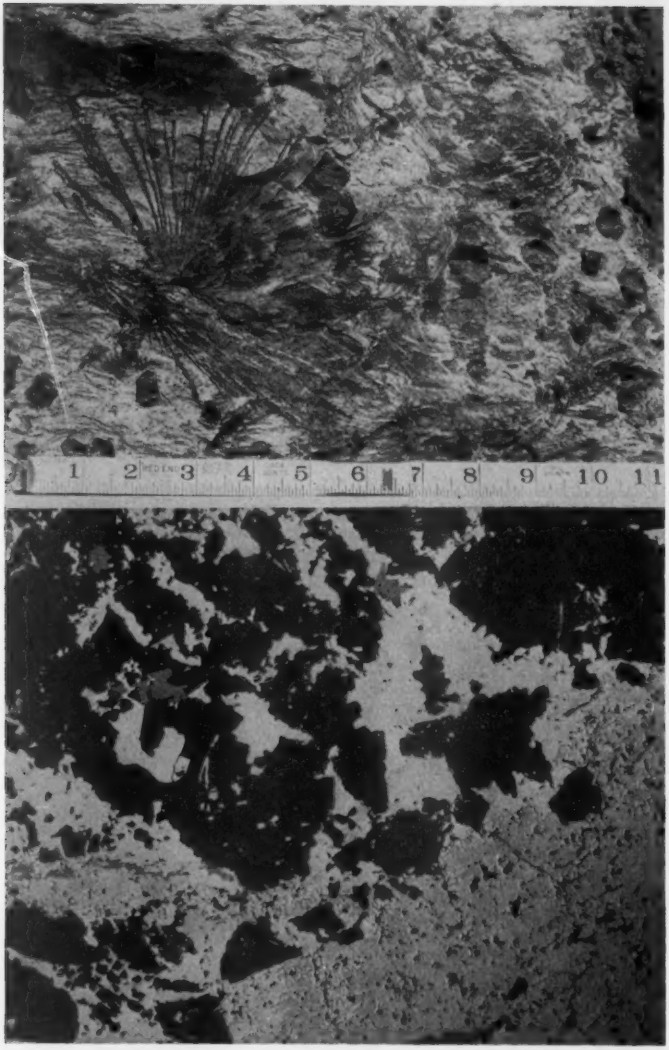


FIG. 16 (upper). Rosette of biotite ps. hornblende, with large garnets in thoroughly sericitized matrix.

FIG. 17 (lower). Sulphides (white) in zone adjoining a pre-ore fault. Note ragged front of attack by sulphides against previously brecciated fragments of rock material. Polished section × 50. Photo by A. R. Smith.

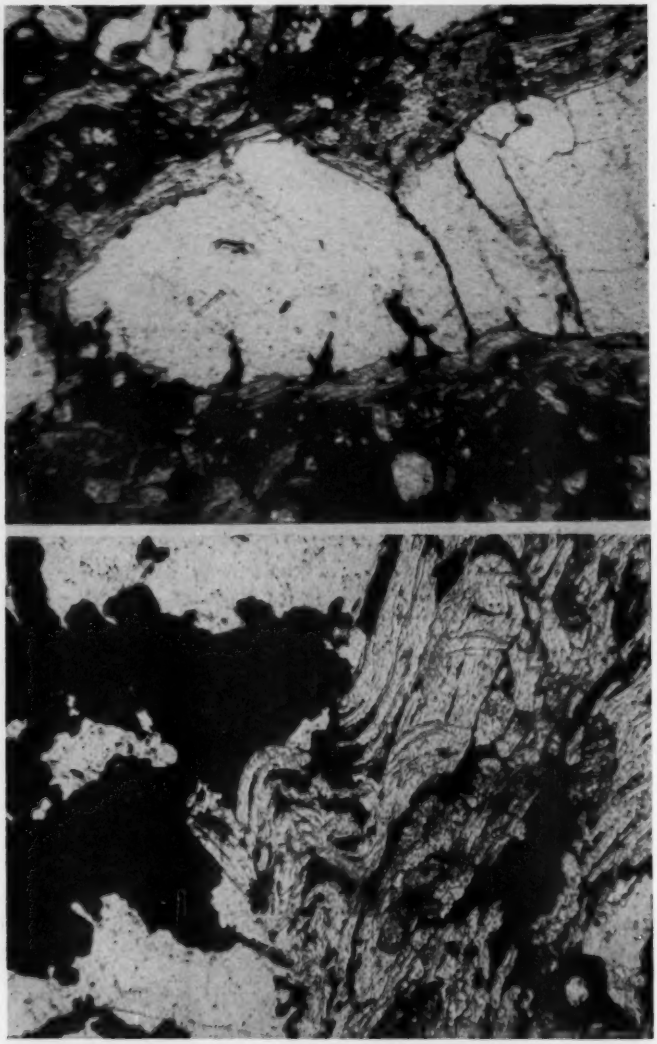


FIG. 18 (upper). Sulphides (black) replacing a broken lens of quartz (white). Thin section × 50. Photo by A. R. Smith.

FIG. 19 (lower). Enlargement of part of Fig. 18 showing sulphides replacing quartz and bent muscovite plates × 150. Photo by A. R. Smith.

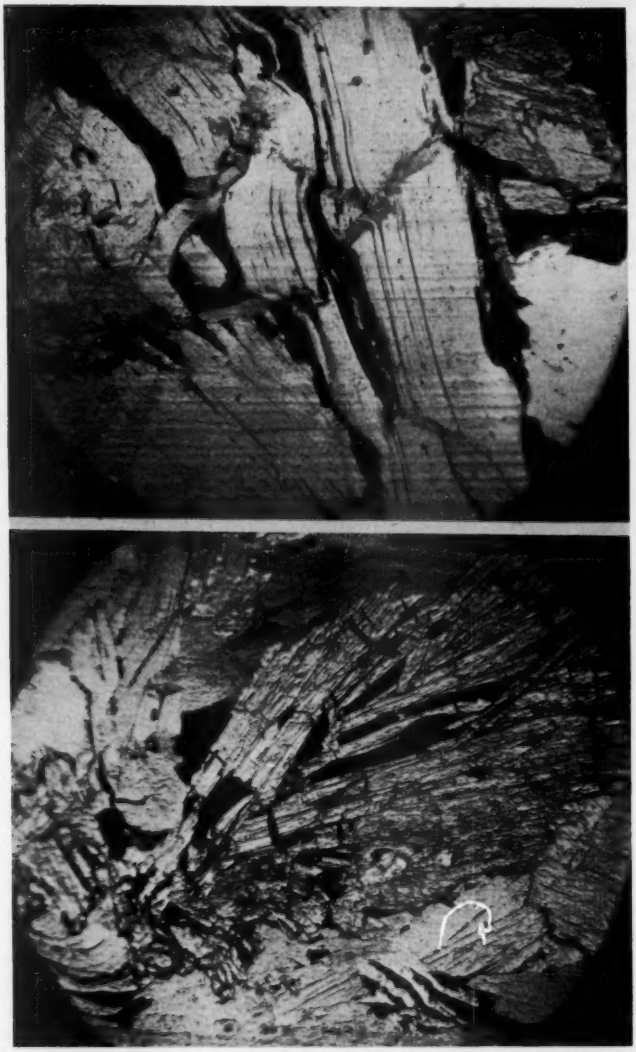


FIG. 20 (upper). Cracks in bent phlogopite crystal filled by sulphides (black). Thin section × 30. Photo by Mikkola.

FIG. 21 (lower). Cracks in bent tremolite aggregate filled by sulphides (black). Thin section × 30. Photo by Mikkola.

Diopside is sparsely distributed in the rock but is best developed around certain quartz veins where it forms massive greyish-green aggregates. Some crystals are as much as 25 mm long.

Pre-Ore Pegmatite Dike.—A pegmatite dike 2 to 3 feet wide occurs in the immediate west wall of the ore zone in the northern part of the mine. Farther south, traces of it appear within the ore zone, and in the south end of the mine it is found on the hangingwall side of the ore bands. The dike is made up of plagioclase (An_{28}) in grains up to 2 inches in size, together with coarse glassy quartz and carbonate with indices corresponding to ferroan dolomite ($\omega = 1.695 +$, $\epsilon = 1.510 +$).

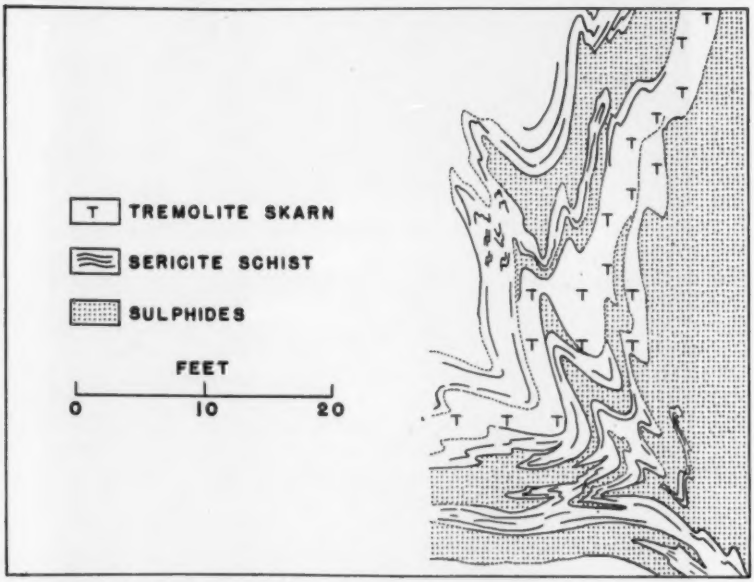


FIG. 22. Selective replacement of folded beds by sulphides. Sectional view. 500 Raise at 15,000 N, elev. 580 feet.

Footwall Sequence.—West of the ore zone, in places separated by several feet of sericitized schist, is an amphibolite member similar to No. 2 of the footwall sequence but generally thinner. We are calling this the Westwall Amphibolite. It appears to grade northward along its strike into a schist or gneiss containing quartz veinlets and some hornblende. To the west of the Westwall Amphibolite the rock is normal biotite schist for 100 to 150 feet but several drill holes have reached another band of amphibolite bordered by a new zones of sulphide mineralization not yet well explored. This Footwall

Amphibolite is tentatively construed as the stratigraphic equivalent of the Hangingwall Amphibolite, repeated on the west limb of the syncline.

Structure.

The Elizabeth Syncline.—The structure of the rocks is best indicated by the amphibolite member(s). The member known as the Hangingwall Amphibolite shows folding characteristic of the east limb of a syncline (Figs. 5 to 8). The folds plunge northward at about 12 degrees and their axes are overturned to a dip of about 65 degrees (locally as flat as 45 degrees).

The full shape of the syncline is not completely revealed because there are few drill holes and fewer long crosscuts into the footwall of the ore zone, but the present interpretation is shown in the cross sections, Figures 5 to 8. According to this interpretation the west limb of the syncline is marked by the Footwall Amphibolite which is merely the Hangingwall Amphibolite repeated on the opposite limb of the syncline. The Westwall Amphibolite is a separate and higher stratigraphic horizon forming a tightly compressed double limb in the center of the fold.

This interpretation is not the only possible one. Preparation of the cross sections has necessitated considerable projection of a multitude of observations up or down the plunge to the planes of the sections; consequently the accuracy of the sections depends on the correctness of assumptions regarding degree and direction of the plunge; out of many trials, those adopted seem to give the best fit.

Alternative Interpretation.—Pending more complete data from drilling and development, at least one alternative interpretation is possible, namely that the Westwall Amphibolite should be correlated with the Hangingwall Amphibolite, thus forming the west limb of a still tighter syncline. The Footwall Amphibolite would then be the limb of another fold.

Not to belabor all of the pros and cons, one principal reason for preferring the first alternative is that the ore zone as exposed in No. 1 and No. 2 Open Cuts has, like the Hangingwall Amphibolite, the shape of a fold, dextral [8] in plan and appropriate to the east limb of a syncline. The ore zone here is both underlain and overlain by amphibolite bands, *both* of which show the same sense of folding (Figs. 6, 10), thus indicating that there are two amphibolite members (namely Footwall and Westwall). If there is only one amphibolite (as permitted by the second alternative) the stratigraphy is, of course, simpler but the structure is more complicated; it would call for a syncline whose axial plane had itself been dragfolded by a shearing movement in which the hangingwall (east) block had moved downward and southward. This would in no sense be impossible and would in fact be concordant with the regional structure. The choice between these alternatives can best await development now in progress in the footwall rocks. Meanwhile for descriptive purposes the first interpretation will be followed.

Structure in the Ore Zone.—In the ore zone the structure is complicated both by cross folds and by faults. Cross folds, in the sense used here, are

[8] A dextral fold, in the usage of White and Billings (12, p. 668), is shaped in plan like a Z, the top and bottom bars of the Z being the long limbs of the fold.

folds whose attitudes are not parallel with those of the main folds. Some of them, at least, have been produced by folding of older axial planes (Fig. 9b). In extreme cases the axial lines of older folds have been twisted. The result is so complex that it is sometimes impossible to correlate folds in one crosscut or raise with those in another only 30 feet away. In general the cross folds have steeper plunges and more easterly strikes than the main folds but there are many exceptions; any consistent interpretation of the geometry and mechanism of cross folding must await further study. Deformation of cleavage might serve as a guide to distinguish younger folds from rotated original folds except that many of the cross folds have developed new axial-plane cleavages of their own.

Faults.—Faults of pre-mineral age are common. Faults of post-mineral age are more conspicuous but, with very few exceptions, their effect has not been great enough to occasion any discontinuity in stoping. Most faults of both types are strike faults with easterly dips ranging from vertical to 50 degrees or less.

In the ore zone, strong faults and shears may constitute either the hanging-wall or the footwall of the ore but, contrary to earlier ideas, there is no single shear with which the ore is consistently associated. Rather there is an *en echelon* set in which individual faults strike slightly more westerly than the nearly north-south trend of the zone as a whole, though exceptions in the form of branches and erratically striking faults are too numerous to permit any very consistent generalization.

Most pre-mineral faults seem to have caused little displacement; some very impressive-looking ones die out into folds along their dip or strike. Apparently they have resulted merely from adjustments along beds during folding. Nevertheless, the aggregate deformation achieved by faulting and cross folding was doubtless large, though its actual amount and sense have not been determined with assurance.

Faults with *post mineral* movement locally contain open vugs lined with crystals of calcite and pyrite; elsewhere they are water-bearing gouge seams. The most conspicuous post-mineral fault is one in the northern end of the mine which has a flatter easterly dip than the ore zone and displaces it about 50 feet in a normal sense. But since there has clearly been post-mineral movement on a number of the pre-mineral faults, the actual amount of post-ore displacement may be smaller than it seems.

Orebodies.

Shape and Size.—The main oreshoot plunges northerly in accordance with the folding but, as shown in Figure 3, its plunge flattens and becomes gently southerly in the northern end of the mine. The local plunges of folds serve as guides to these variations. The top of the oreshoot is formed, at least on the upper levels, by a structural roll (Figs. 6, 10) in which the Westwall Amphibolite wraps over the top of the shoot. The bottom of the shoot coincides with its approach to the bottom of the syncline. From its exposure in Open Cut No. 1 to the north end of the 975 level the shoot measures over 6,000 feet

in pitch length. In thickness the ore as mined averages about 20 feet but in places reaches 50 feet or more.

South of No. 2 Open Cut another oreshoot had been mined, in the South Mine. It is localized by drag-like folds which likewise plunge northward, probably with some undulation. Its continuity in depth, where it should extend below the main oreshoot, has not been thoroughly explored; its average copper content, so far as known, is lower than that of the main oreshoot.

Thus the length throughout which sulphides are probably continuous though perhaps not continuously mineable as copper ore is at least 8,300 feet.

Sulphides.—Pyrrhotite constitutes nearly 90 percent of the sulphide matter and chalcopyrite about 9 percent, although these proportions vary in dif-

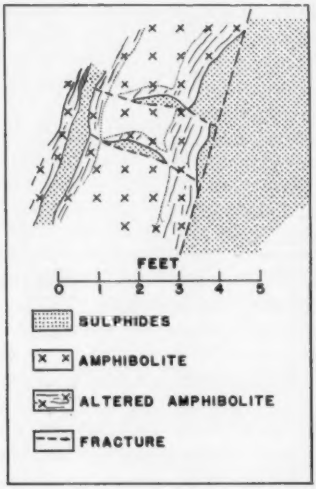


FIG. 23. Fracture in amphibolite band filled (partly replaced?) by sulphide. Cross section looking south. 300–020 Raise at 10,145 N, 10,000 W, elev. 1,305 feet.

ferent parts of the ore body. The ore as mined, including unavoidable dilution by wallrock, contains 25 to 75 percent of pyrrhotite and averages roughly 35 percent (1, p. 23); the millheads carry about 21% Fe and 13% S.

The ore contains about 0.4 percent zinc and small amounts of precious metals (2.3 oz silver and .01 oz gold per ton of concentrate, corresponding to a recovery of 0.16 oz silver and 0.008 oz gold per ton of ore mined). Spectroscopic analysis [9] indicates that the ore contains about 0.1 percent each of nickel and cobalt and traces of Sb and Ti but no Sn, Bi, Cr, Be or Ba.

[9] By John Rabbit in the Mineralogical Laboratory, Harvard University, 1942. The analysis reports no Mo although molybdenite does occur in the ore; presumably the samples were not fully representative.

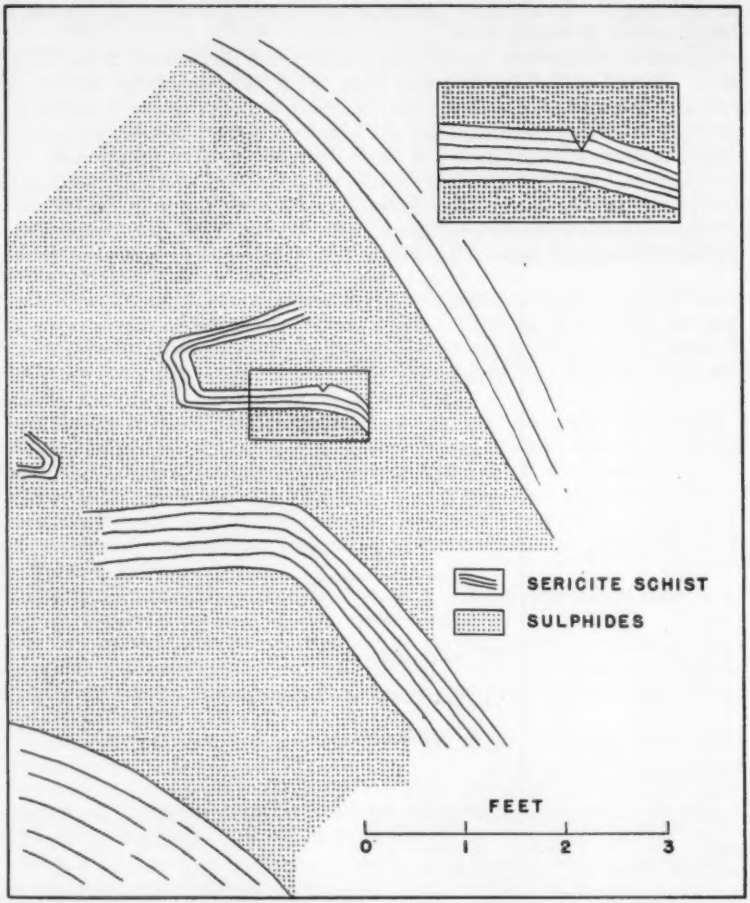


FIG. 24. Bands of deformed schist in massive sulphide. Rectangle at upper right corner is enlargement of a wedge-shaped crack in a bent band. Cross section looking north, 975 level at 14,050 N.

The *pyrrhotite* is only feebly magnetic; measurements of magnetic susceptibility [10] indicate about .015 cgs. units. Susceptibilities for ore from Pike Hill are even lower, about 0.0015. The atomic proportion of Fe to S in the pyrrhotite, as calculated from assays of drill cores and mill products, is very close to 1:1.

As seen in polished section, the grains of pyrrhotite range from 0.1 mm to

[10] By Dr. Lucien Masse of Weiss Geophysical Corporation. Private report.

several mm. Pyrrhotite is one of the earliest ore minerals, replacing pyrite but replaced by other sulphides.

Chalcopyrite grains range in general from 0.1 to 0.5 mm in diameter, but tiny grains 0.01 mm and smaller are intimately associated with pyrrhotite.

Chalcopyrite in one locality has fracture-like bands occupied by pyrrhotite and sphalerite; chalcopyrite in other specimens collected nearby contains lamellae of *cubanite* up to 0.5 mm wide, relations that suggest exsolution of other minerals from chalcopyrite.

A mineral doubtfully identified as *valleriite* occurs within chalcopyrite, in fracture-like bands .05 mm wide and 0.2 mm long. Because of its small amounts it has not been definitely identified, but its strong anisotropism and its etch reactions correspond to valleriite.

Sphalerite is disseminated extremely sparsely among other sulphides. It may be enclosed in pyrrhotite but is more commonly associated with chalcopyrite. Oval aggregates of it in massive ore show evidence of replacement by chalcopyrite but where the sphalerite is in single grains, the borders against chalcopyrite are "mutual."

Pyrite is very sparse, forming cubes from microscopic size up to 5 cm, with their corners slightly rounded against other sulphides. Fractures in them and interstices between grains are filled by pyrrhotite.

Galena is very scarce and is seen only in polished sections where it appears in isolated grains 0.05 to 0.1 mm in diameter along with other sulphides.

Tennantite and *tetrahedrite* are exceedingly rare and were identified with certainty in only one of 25 polished sections studied. Presumably they account for the small amounts of silver and antimony in the ore.

Gangue Minerals.—Veins and masses of quartz are common in the ore zone; some of them are merely the same bodies of coarse quartz so common throughout the metamorphic schists but most of them consist of finer grained vein quartz, either as bands outlining the folds or as definite crosscutting stringers. Although the vein-quartz is chiefly confined to the ore zone, it is earlier than the sulphides and bears no consistent space-relations to them.

Tourmaline and subordinate idocrase [10] form prisms in the wallrock, chiefly in the south end of the mine. Characteristically, chalcopyrite is molded on them. Rutile, although quite sparse, is widely distributed in the ore, as well as in the calcite of the pre-ore pegmatite vein.

Tourmaline and rutile, although earlier than the sulphides, appear to have been introduced in connection with mineralization as they have not been found away from the ore zone; they commonly fill cracks in the rock, in places along with quartz, and pyrrhotite.

Sequence.—In the following listing of minerals in their apparent sequence of deposition, species bracketed together are contemporaneous or overlapping:

Gangue Minerals: (quartz, feldspar, tourmaline, rutile)
Sulphide Minerals: pyrite, pyrrhotite, (sphalerite, chalcopyrite), (galena, tetrahedrite, tennantite)
In post-ore faults: calcite, pyrite.

[10] First recognized by Dr. J. B. Thompson.

Molybdenite is probably an early mineral but its position in the sequence is hard to fix.

Wallrock Alteration.—Alteration of the rocks in and adjoining the orebodies consists primarily of sericitization and silicification, the particular type of alteration depending partly on the nature of the wallrock; biotite schists and quartzite are sericitized, whereas amphibolites are silicified, but extreme alteration of amphibolite can also result in sericitization.

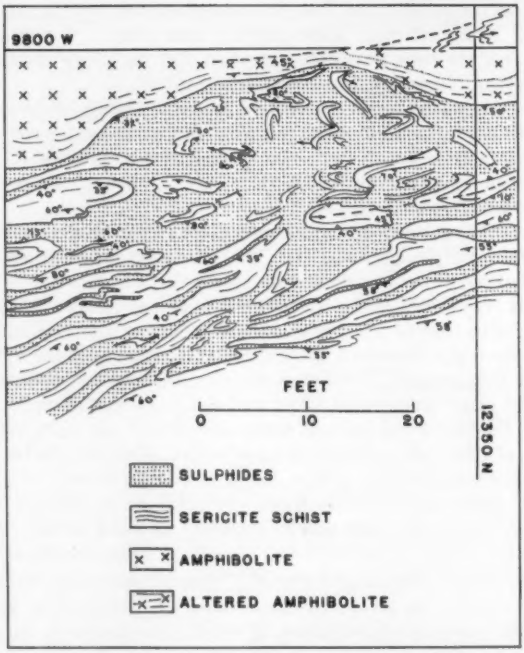


FIG. 25. "Schist breccia." Inclusions of deformed schist in sulphide. Plan of back in 975–250 stope at elev. 665 feet.

In *Biotite Schist and Quartzite* sericitization of original plagioclase and biotite results in a rock consisting of 45 to 90 percent sericite. The black biotite of the original rock is converted to sericite and any biotite that survives is bleached to a light brown color. Much of the sericite appears to be pseudomorphic after the original biotite and, like it, occurs in the interstices between quartz and plagioclase and in streaks along the cleavage.

The original plagioclase is sericitized to a degree that depends on distance from the sulphides. The grains of feldspar, although turbid and corroded by quartz and sericite, are still recognizable by their shape and in some cases

by their twinning. Saussuritization, though observable, is subordinate to sericitization.

The rock adjoining the sulphides in most places is laminated schist consisting of bands alternately rich in sericite and quartz. A special type of altered rock mapped as "spotted schist" is characterized by small aggregates of biotite in places with a hexagonal shape resembling the cross section of a garnet crystal and rarely containing unaltered garnet in their centers. Evidently the spotted schist is derived from a biotite schist or quartzite containing small garnets. There is a strong suggestion that it is a less intense phase of alteration than the laminated schist, which in most places adjoins the ore, though locally spotted schist is next to the sulphides.

In *Amphibolite* intensity of alteration is expressed by two zones: an outer zone, indefinite in thickness (since its outer margin is gradational) but of the order of 1 to 1.5 feet wide, and an inner zone about 0.5 feet wide next to the sulphides. The outer zone adjoining the fresher rock is strongly schistose and consists largely of reddish-brown biotite with considerable carbonate. Remnants of light green hornblende are replaced by quartz and plagioclase and are often surrounded by fine grained biotite. The carbonate, similar to the carbonate in the unaltered rock, occurs in euhedral metacrysts 2 to 5 mm in diameter, corroded, like the hornblende, by quartz and plagioclase.

The more intensely altered inner zone, next to the sulphides, is strongly laminated, with alternating 1 mm. bands of quartz and biotite respectively. Stages in alteration are shown in Figures 12 to 14. In the quartzose bands two generations of minerals can be recognized. The older generation, consisting of aggregates of quartz showing undulatory extinction together with large plagioclases, is replaced by a younger generation of quartz in closely packed euhedral grains 0.5 mm in diameter together with a few plagioclase grains (An_{20-25}) of about the same size. Unlike the older plagioclase they are not sericitized. The biotite lamellae, made up of flakes 1 mm long in parallel arrangement, give the rock its schistosity. Some of the biotite is altered with fading boundaries into sericite. Some chlorite replaces biotite but more of it replaces hornblende prisms.

The alteration products of both zones contain accessory rutile, chiefly in the biotite bands, and also epidote, tourmaline, and apatite.

The alteration of amphibolite containing large radiating crystals of hornblende is very striking (Fig. 16). The hornblendes are converted to rosettes of biotite, enclosed in quartz, biotite, sericite and plagioclase. Where alteration has continued further, the matrix is completely bleached by sericitization of the biotite, while the dark rosettes still remain recognizable. Garnets, where present in this rock, are remarkably stable, surviving after the matrix has been thoroughly sericitized. They are generally surrounded by rims of quartz 1 to 1.5 mm thick and may have rims of chlorite.

As a rule, alteration does not obliterate all of the textural features except in the few inches adjoining the ore but in some places sericitization has completely destroyed the original rock. This has happened notably in No. 2 open cut where the Westwall Amphibolite lies in flattish rolls overlying the orebody.

In brief, the alteration of amphibolite results in a decrease in hornblende

and black biotite and an increase in reddish biotite and quartz. With more intense alteration the biotite is sericitized.

Phlogopite-Tremolite Rock in places acquires a slightly laminated texture with introduced quartz and resembles the laminated zone in the amphibolite. Flakes of phlogopite are marginally bleached. Plagioclase is strongly sericitized and saussuritized. Tremolite is altered into talc along its edges and

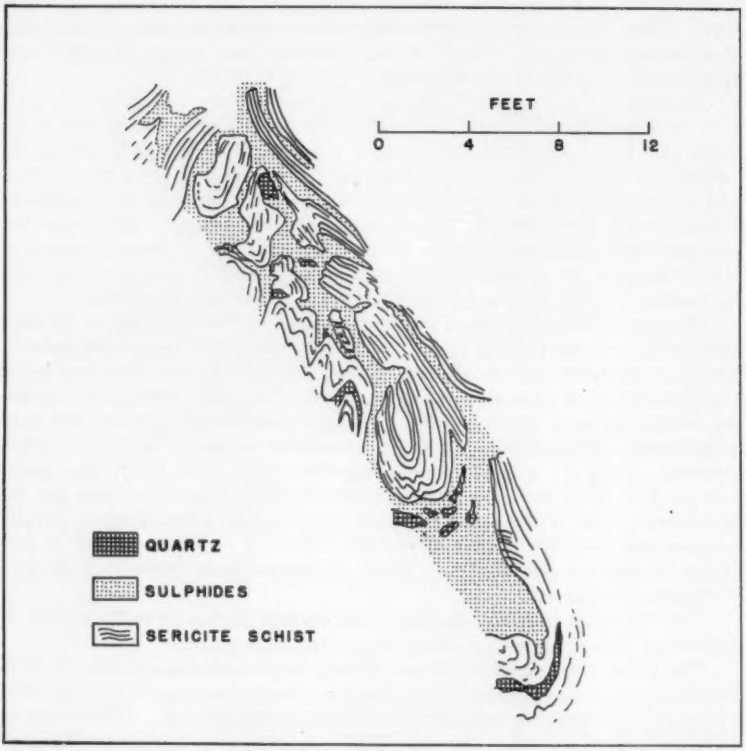


FIG. 26. Breccia of schist fragments in matrix of sulphides. (See text.) Cross section looking north. 480 Stope Raise at 14,970 N.

cleavage planes. Carbonate of an early generation in anhedral crystals 5 to 7 mm in diameter is darkened by impregnation with fine grained sulphides and replaced by tremolite and phlogopite. In places, the old carbonate grains are surrounded by rims of clear carbonate 1 to 2 mm thick. Coarser sulphides crystallize between the carbonate grains that form the rim but do not invade the grains themselves.

In *Pre-Ore Pegmatite* the alteration of the large (1 to 2 inch) carbonate grains is rather extraordinary. Typically the creamy white center of a crystal is surrounded by a 1 mm halo of carbonate darkened by fine grained opaque inclusions. This in turn is surrounded by a rim of fibrous wollastonite and fine grained phlogopite. Some carbonate grains are completely replaced by wollastonite. These relations are typical of the north end of the mine; in the south end the replacing silicate, instead of wollastonite, is tremolite-actinolite of the same type that appears in the hydrothermally altered carbonate of the amphibolite. Similarity in the patterns of tremolite and wollastonite suggests that the wollastonite may belong to the ore-forming period.

The oligoclase crystals have been rendered greenish and turbid by sericitization. Where the pegmatitic material has been included in ore, the plagioclase remains "floating" in the sulphides, retaining sharp crystal faces, though cracked by sulphide-filled fractures.

Mode of Emplacement of Sulphides.

Structures in the ore zone indicate that both replacement and open space filling have been active in the introduction of the ore.

Replacement on a major scale is especially evident where the ore is in sericite schist; there, remnants of schist survive to advanced stages of replacement. There are all gradations from sulphides disseminated in the schist—most abundantly along bands parallel to the schistosity—to bands of nearly solid sulphide enclosing whisps of schist. Bands of sulphide are concordant with folds, commonly displaying intricate shapes unexplainable by any mechanism of fracturing alone (Fig. 22). In the extreme case of virtually massive sulphide, the original structure of the rock is commonly preserved as ghost-like remnants of schist or even as a banded alternation of pyrrhotite and chalcopyrite.

Old gouge zones along pre-ore faults show evidence of replacement by sulphides. Angular to sub-rounded particles of the rock minerals .05 mm to 1 mm or more in size have been attacked; rhombohedral fragments of carbonate are marginally replaced; aggregates of quartz and feldspar have been cracked and replaced in "exploded bomb" texture. Figures 18 and 19 show a band of quartz-feldspar which has been severed in the manner of microscopic boudinage; the cracked quartz and contorted mica in the zone of "necking down" have been replaced by sulphides. In these gouge zones grains of sulphide have irregular outlines and show no evidence that they themselves have been crushed or sheared by any post-ore fault movement (Figs. 15 and 17).

In contrast, sulphides along post-ore faults show noticeable evidence of deformation. Pyrite crystals are cracked and pyrrhotite grains have developed flamboyant twinning. Fractures in both minerals are filled by lighter colored pyrite associated with calcite.

Open Space Filling.—Although a large proportion of the sulphide has been introduced by replacement there is evidence that open spaces (or potential open spaces) became available and were filled by sulphide. Filling of fractures is most evident in amphibolite, which has behaved as a relatively competent rock

(Fig. 23). In mica schist, bent bands have broken along wedge-shaped cracks now filled by sulphides (Fig. 24). Mica schist adjoined by amphibolite has developed spectacular breccias with interstices filled by sulphides, as illustrated by Figure 25. Note that in Figure 26 the fragments of schist adjoining the hangingwall are clearly slabs that have been split off and are now separated from the wall by bands of sulphide and that they could be brought back into place by raising each of the fragments and rotating the three upper ones clockwise. Their displacement could have resulted either from slumping into open space or from drag on a reverse-fault. The fragments adjoining the footwall

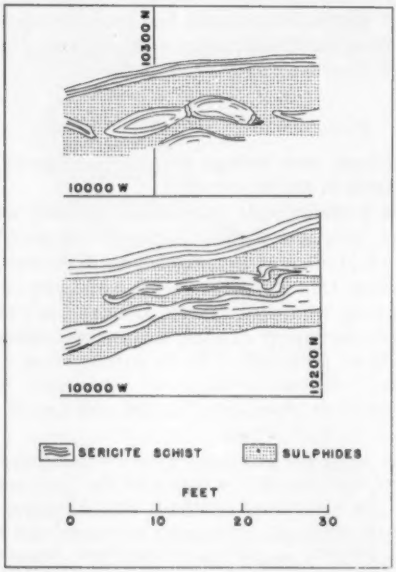


FIG. 27. Schist fragments partly to completely separated in the manner of boudinage and included in sulphide. (White space between the two lenses in the upper sketch is occupied by quartz.) Drift 300 S.

cannot be restored so simply; their schistosity and axial planes are discordant with those in the footwall.

In breccias of this type fragments are commonly detached from their original sites but there is no evidence that they have been moved more than a few feet.

Examples of boudinage are numerous on a major as well as a microscopic scale (Fig. 27). Sulphides enclose the stretched or squeezed bands and surround their severed ends. These bluntly rounded ends can be mistaken for folds because of concentric bands of alteration parallel to their margins.

On a microscopic scale, cracks and "saddle reefs" in bent phlogopite (Fig. 20) and fractures in broken tremolite prisms (Fig. 21) have been filled by sulphides with more or less replacement.

Clearly such features as brecciation and boudinage were developed later than the main folding, but whether the potential openings were immediately filled by sulphides or were occupied by crushed material susceptible to later replacement is not clear.

Distribution of Minerals.—The most noticeable contrast in proportions of sulphides is between the bottom and top of the oreshoot. As used here, "bottom" and "top"do not refer to elevation but to the keel and crest of the plunging shoot; thus on any one level the southern end of the shoot is the bottom or keel, the northern end is the top or crest. Along the axial line of the shoot there is little variation; mineralization in the keel of the shoot is much the same at the south end of the deepest level as at the surface; likewise the northern ends of all levels are apparently much alike although our information regarding levels other than the 975 (bottom) is meager because they are mainly inaccessible at present.

Chalcopyrite is most abundant in the middle and top of the shoot; in fact some of the ore richest in copper has come from stopes near the very crest of the orebody. It is relatively sparse where the workings are in and near the keel; large tonnages of massive pyrrhotite here are not payable without revenue from iron and/or sulphur. Pyrite is also more abundant near the north end where locally it forms heavy concentrations. Sphalerite, although present in small amounts throughout the oreshoot, is found in almost massive form in a band 0.5 to 1 foot wide on the 300 level stope near coord. 10200 N; similar concentrations also in the south end of the mine have been seen in drill cores. Molybdenite, while occurring very scantily in all the ore, is most abundant in the stope just mentioned, associated with pre-ore carbonate and in drill holes along with pegmatitic plagioclase, all in the south end.

Discussion.—An inquiry into the distribution of minerals in and around the oreshoot calls for consideration of alteration minerals and gangue minerals as well as sulphides. The observed occurrences are as follows:

	South End (bottom)	*North End (top)*
Alteration	Mainly silicification and biotitization	Mainly sericitization (some silicification)
	Tremolite rims on carbonate	Wollastonite rims on carbonate fragments
Gangue Minerals	Tourmaline and idocrase	Tourmaline rare or absent Idocrase not seen
Sulphides	Massive pyrrhotite (some chalcopyrite)	More chalcopyrite
	Local concentrations of molybdenite and sphalerite	Local concentration of pyrite

Although some of these relationships seem somewhat contradictory, it does appear that minerals early in the sequence are more abundant in the south end (or bottom) of the ore shoot whereas the late minerals—species generally regarded as characteristic of relatively low temperature—are more abundant in the north end or top.

In respect to rock alteration, the contrast can be attributed partly to difference in the original nature of the rock. At the south end the ore is chiefly in tremolite-phlogopite rock close to amphibolite whereas in the north end much of it is in altered biotite schist. To appreciate the resulting contrast in response to alteration it is worth while to consider the chemistry of the process. The principal reactions were addition of H_2O, K_2O and SiO_2 together with removal of iron, some or all of which is presumably fixed nearby as pyrrhotite. By these reactions, hornblende and garnet can eventually be converted to sericite but they must first be made over into biotite by addition of H_2O and K_2O. As this calls for one more step in the process of alteration than does the sericitization of schist that already contains plenty of biotite, it must require either higher concentrations of H_2O and K_2O or longer exposure to altering solutions. It is therefore understandable that at a given stage in the process of alteration, amphibolites may have reached only the biotite stage whereas biotite schists have been completely sericitized. Hence the contrast in alteration between the south end of the mine and the north end is not necessarily caused by the difference in the temperature or composition of the solutions accomplishing the attack. Nevertheless, some of the most strongly sericitized amphibolite is found in the top of the orebody in No. 2 Open Cut where amphibolite forms the overwall above the orebody.

The arrangement of other minerals further suggests a contrast in the nature or degree of alteration and mineralization. The abundant plagioclase in the ore zone at the south end of the mine may perhaps represent a variation in mineralogy of the metamorphic rock but its survival surely indicates that conditions were not as conductive to sericitization as in the south end. Similarly tourmaline, so common at the south end, would not be expected to crystallize in the presence of potash-rich altering solutions within the lower temperature range and, in fact, it is not found in the north end. Prevalence of chalcopyrite in the north end and near the top of the shoot is harmonious with the observation in other districts that chalcopyrite seems more fugitive than pyrrhotite, occurring more abundantly in the outer parts of pyrrhotite bodies and extending farther into the wall rock. Pyrite does not fit so neatly into this scheme as it is concentrated near the top of the shoot, yet seems to be early in the sequence. However, its deposition in lieu of pyrrhotite is favored by high vapor pressure of sulphur (4). But the wollastonite rims on carbonate at the north end as compared with tremolite rims at the south end still seem enigmatic.

Despite exceptions, the general contrast in mineralization between the bottom and top of the oreshoot is consistent enough to indicate a difference in conditions of mineralization and to call for explanation.

Some of these relationships might suggest zoning except that the distance between the bottom and top of the shoot is insufficient for much difference in temperature at any one time. Difference in wallrock, which helps to explain contrast in alteration, might conceivably be responsible for difference in proportion of sulphides though it is hard to see why it should.

While no thoroughly satisfactory explanation is forthcoming the general relations suggest that solutions capable of altering the rocks and precipitating

late minerals were more abundant or had longer duration of flow near the top than near the bottom. The direction of flow of solutions is unknown but it is more plausible that they flowed up the plunge of the shoots than vertically up or up-and-north where they would have to pass through little-altered rock to gain access to the site of deposition. It is conceivable that during the progress of mineralization the path of maximum flow was shifted progressively upward, possibly through mineralization-stoping, or that more volatile constituents sought the upper part of the channelway.

Structural Localization of Sulphide Bodies.—The position of the main ore shoot is determined by a favorable combination of stratigraphic horizon and deformation. The stratigraphic member most amenable to replacement is the tremolite-phlogopite schist with its abundant carbonate. Where it has been deformed, the adjoining beds of mica schist have been sheared, strongly contorted, and brecciated. This condition is most marked in the strong zone of deformation adjoining the Westwall Amphibolite. In the present interpretation this is zone of slipping between competent and incompetent members on the long straight limb of a fold. Along this zone, intervals of thinning alternate with intervals of complex doubling and drag folding. In such places not only has the doubling-up caused a repetition of favorable members but the attendant crumpling has caused brecciation, allowing still more opportunity for broad mineralization.

Wide sections of ore, as seen in No. 1 and No. 2 open cuts as well as in the South Mine, are at places of thickening on dextral drag folds.

AUTHORSHIP AND ACKNOWLEDGMENTS.

One of the authors (McKinstry) has made extended visits to the property at intervals since 1949 as consultant to the Vermont Copper Company. The other author (Mikkola) did geological work at the mine in the summer of 1951 and has been there as full time geologist since July 1952. For workings now inaccessible we have made free use of maps and sections prepared by H. M. Kingsbury. Alfred Wandke, Jr., and Arthur R. Still carried out mapping and geological studies at various periods. H. Gassaway Brown, geologist 1951–1953, has done much underground mapping and logging of drill core. We are indebted to him for drafting most of the illustrations in this report. Richard Little, Chief Engineer, took the photographs, with the exception of the photomicrographs, some of which were made by A. R. Smith.

We are deeply indebted to John F. Cowley, President of the Vermont Copper Company, for permission to publish this description.

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Harvard University,
Cambridge, Mass.,
and
Vermont Copper Company,
South Strafford, Vt.,
August 23, 1953.

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OCCURRENCE AND ORIGIN OF THE GRAPHITE DEPOSITS NEAR DILLON, MONTANA.

ROBERT B. FORD.

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ABSTRACT.

The probable origin of the graphite at the Crystal Graphite mine near Dillon, Montana, has often been discussed in the geologic literature. Heretofore those writers who have advanced any theories of origin have all concluded that the graphite is genetically associated with the granitic pegmatites of the area.

Field and laboratory work done in 1950 is discussed herein. It is concluded that the graphite mineralization is much later than any period of metamorphism or pegmatite emplacement. These deposits also show structures and textures typical of epithermal mineralization. They therefore require an hypothesis of origin divorced from any genetic association with the pegmatites of the property.

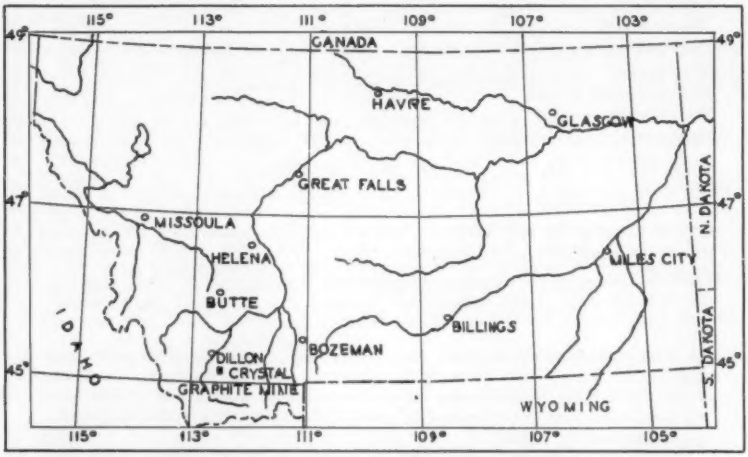
INTRODUCTION.

THIS paper considers the diverse opinions on the genesis of the graphite at the deposits of the Crystal Graphite Company, near Dillon, Montana. Review of the geological literature and study of the deposits have disclosed features of the graphite occurrence that are not in agreement with the findings of previous investigators. In particular, the relationships of the graphite deposits to the pegmatites present in the area appear to be different from those previously reported. These features are discussed below.

The paper is based on field study of the deposit during July 1950, together with laboratory studies of a suite of specimens of the graphite-bearing materials

and associated rocks collected at that time. The writer is indebted to Dr. E. N. Cameron, Geology Department, University of Wisconsin, for outlining the problem and making the study possible, and to the University of Wisconsin for use of the laboratory facilities.

Location.—The deposits owned by the Crystal Graphite Company are located at the southern end of the Ruby Range, thirteen miles southeast of Dillon, Montana (Fig. 1). The deposits lie on the ridge between Axes Canyon and Timber Gulch. There are two separate groups of workings; the oldest are on the Birds Nest Claim along the southeast side of Axes Canyon, 3,200 feet northeast of Crown Point. Three adits have been run at different levels along a dry gulch between Axes Canyon and Craggy Point. Square sets at the en-



INDEX MAP OF MONTANA SHOWING LOCATION OF CRYSTAL GRAPHITE MINE

FIG. 1.

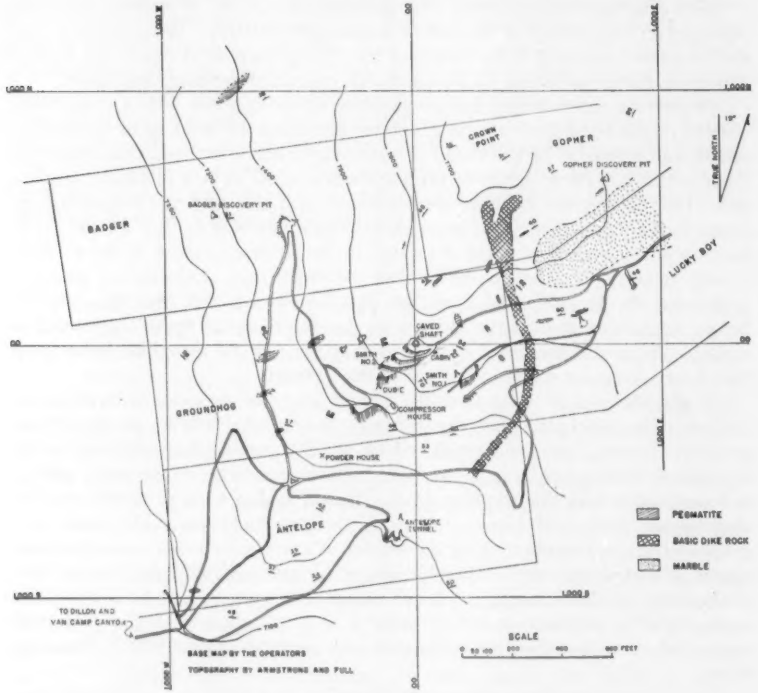
trances of all the adits have caved so that the workings are inaccessible beyond the first 20 to 30 feet.

The second and more important group of workings lies southeast of Crown Point in sections 29, 30, 31 and 32; T. 8 S., R. 7 W. These workings are reached by road through Van Camp Canyon and then by switch-back trail above the mill. There are stoped veins on all but the lowest level; all workings are located within the Badger, Groundhog, and Antelope claims (Fig. 2).

Development.—Although no data regarding past production are on record, it is known that the first shipment of graphite was made in 1902 and that it came from the Birds Nest workings. It has been estimated, however, that only fifty tons were taken from these workings. From 1902 until the war

operations began in 1941, the main workings produced a little over 2,000 tons of graphite. Most of this production was during World War I.

The main workings are mostly within the Groundhog claim and consist of both new and old adits connected by raises and shafts. The lowest adit is on the Antelope level, which was driven after the mine reopened in 1941. The adit is about 1,000 feet long, and is driven into the southeast side of the spur



CRYSTAL GRAPHITE MINE

FIG. 2.

in which the deposits are located. It trends northwest; its inner end just intersects the graphite-bearing zone. No stoping has been done from this level, and only the extreme northwestern end of the adit intersects coarse flake or vein-type ore. The Dubie adit was driven at a level 240 feet above the Antelope level. It has probably yielded only a small tonnage, for stopes from this level are few and small. The Smith level is fifty feet above the Dubie level. Much stoping has been done from this level, and much vein type ore

is exposed in its walls. Much of the Smith level is inaccessible, as stopes opened from it are caved through to the surface. An old level, the Hoy, is accessible only from the Dubie workings above it. Two short unnamed adits to the west enter the "injected gneiss," but little vein type ore is exposed in their walls.

Previous Work.—The graphite deposits near Dillon, Montana, have been studied by Winchell, Bastin, Armstrong and Full, and Heinrich.

The graphite deposits were first described by A. N. Winchell (4),[1] who reported on the geology of the Dillon quadrangle in 1910. Winchell described the limestones exposed at the mouth of Van Camp Canyon as repeatedly faulted Paleozoic rocks underlain by Precambrian quartzites, schists, and slates.

In postulating an origin for the graphite at the deposits near Dillon, Winchell (5) considered the seams of graphite paralleling the bedding in the marble, schist, and gneiss to be the result of metamorphism of carbonaceous layers in those rocks, and the graphite of pegmatites and veins to be a primary constituent. He thought the intimate association of graphite with the pegmatitic igneous facies was sufficient evidence that the graphite was neither a later introduction into the rock, nor had it existed in the silicate solution in the form of crystal flakes. Winchell believed that the refractory character of graphite prohibited the formation of liquid or gaseous carbon and that the graphite before deposition must have existed in the solutions as some compound of carbon. Winchell therefore concluded that the Crystal Graphite mine illustrated two different modes of origin of the graphite.

E. S. Bastin (2) compared the Dillon graphite deposits with those of Ceylon. He concluded that the contact metamorphic effects at the Dillon graphite deposits had been produced by granitic pegmatites previous to the deposition of the graphite in those rocks. Bastin found no metasomatic alteration associated with the graphite veins. Bastin agrees with Winchell that the distribution of the graphite is related to the granitic rocks. He states that graphite is more abundant along the border of granitic masses or along certain planes within them, which resemble planes of magmatic flowage rather than of shearing. Bastin disagrees with Winchell, however, in that he believes the most probable explanation for the source of the carbon is that carbon was abstracted from carbonaceous sediments by a granitic magma which traversed them.

The Crystal Graphite mine was examined in May 1945 by F. C. Armstrong and R. P. Full (1) of the U. S. Geological Survey. The surface outcrops and underground workings were mapped in detail. Armstrong and Full recognized that the most important structure in the area is a fracture zone developed in an isoclinal fold of schists, gneisses, and marble. The gneisses fold around the southwest end of a marble nose that outcrops on top of the spur southeast of Crown Point. The parallel limbs of the fold strike about N 50° E and dip about 45° NW. The dip and direction of the plunge of the fold were found to be about 45°, N 20° W.

No theories of origin were advanced by Armstrong and Full other than the belief that all the graphite was formed at approximately the same time.

[1] Numbers in parentheses refer to Bibliography at end of paper.

The most recent published work on the Crystal Graphite mine has been done by E. W. Heinrich (3) while making a regional study of the pegmatite mineral deposits in Montana. Heinrich proposed an age grouping of the pegmatites of Montana and divided them into (1) pre-Beltian pegmatites, (2) Laramide pegmatites, and (3) pegmatites of Tertiary age. Heinrich believes that the rocks of the Cherry Creek series, which are the principal component of the bed rock complex at the Crystal Graphite mine, were intruded first by pre-Beltian pegmatites, now metamorphosed, and later by Laramide pegmatites with minor aplites. According to Heinrich, pre-Beltian pegmatites form part of the metamorphic sequence, occurring as foliated sills (granulites), whereas the Laramide pegmatites lack this foliated texture and are unmetamorphosed. Both groups of pegmatites are essentially the same in mineralogy. Heinrich regards this chronological classification of the pegmatites as important, and believes the graphite to be intimately related to the Laramide pegmatites. He concluded, therefore, that the carbon was a primary element in the pegmatitic magma, and that the graphite was deposited at a late stage in the consolidation of the Laramide pegmatites.

GENERAL GEOLOGY.

The southern end of the Ruby Range is characterized by Precambrian rocks of the Cherry Creek and Pony series, which are major subdivisions of the pre-Beltian rocks of Montana. In the vicinity of the Crystal Graphite mine, a thickness of about 30,000 feet of the Cherry Creek series has been reported (3). The uppermost part of the series includes several marble horizons that outcrop in Van Camp Canyon. These were the horizons first described by Winchell as repeatedly faulted Paleozoic limestones.

The lower part of the series outcrops at the main workings and is characterized by biotite-garnet gneiss, hornblende gneiss, and marbles. The gneisses have been intimately "injected" by material consisting largely of quartz and feldspar.

Biotite-Garnet Gneiss.—Biotite-garnet gneiss is the most common rock type of the area. It is a strongly foliated rock composed of biotite-rich layers alternating with coarse granitic layers. The biotite lies parallel to the plane of gneissosity. Thin sections show the reddish-brown and yellow pleochroism typical of varieties high in magnesium. In many places, the biotite is frayed and deformed and is altered to chlorite. Pyrope, the high-magnesium garnet, is widely distributed throughout the gneiss. The larger crystals of garnet contain numerous inclusions of quartz and orthoclase typical of that derived from biotite. Garnet has forcibly thrust aside the folia of micas and masses of quartz to form eye structures in the "injected" granitic material. The garnets are anhedral and shattered, but shattering was evidently late, as there is no tendency toward elongation of the shattered portions.

Accessory minerals are orthoclase, plagioclase, quartz, epidote, sphene, sericite, and graphite, the latter developed along minute fractures devoid of gangue.

Hornblende Gneiss.—A layer of hornblende gneiss is prominently exposed

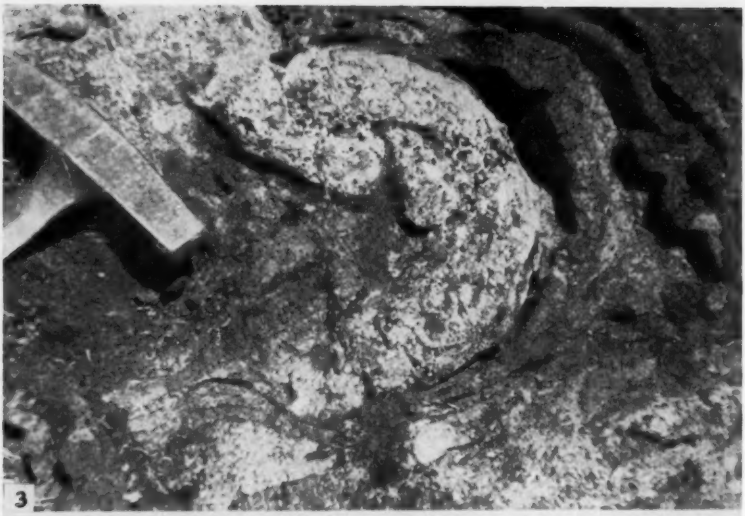


FIG. 3 (upper). Isoclinal folding of marble and pegmatitic stringers showing sharp borders and lack of contact alteration.

FIG. 4 (lower). Shattered zone in lime silicate rock showing development of flake, comb, and rosette type graphite.

on the slope west of the main workings. It is a dark, well-foliated rock consisting of visible black hornblende needles and plagioclase, porphyroblastic in places. The hornblende is olive green in thin section. Little biotite is present, but orthoclase, plagioclase, sericite, chlorite and garnet are abundant. This unit is conformable to the regional foliation and contains layers of coarse granitic material.

Marble.—The marbles range from pure dolomite to rocks that contain calcium and magnesium silicates. The most prominent outcrops of dolomitic marble are those northeast of the main workings, where the marble is folded into a tight isoclinal fold. This marble weathers to a mottled deep-brown granular rock. The nose of this marble fold, which forms the focus of structural control in the main workings, plunges 45°, N 20° W. It is not exposed in any of the underground workings. The marble contains a small number of feldspathic lenses, all less than three inches wide, that pinch and swell with the layering of the marble (Fig. 3). The contacts of pegmatite and marble are sharp without the development of any lime silicates.

Lime Silicate Rocks.—A layer that was originally calcareous but has now been converted to pyroxenite outcrops in a caved stope by Smith Portal No. 1. The rock is highly shattered, and graphite forms scattered irregular pods, rosettes, fracture fillings, and disseminated, isolated flakes along the fractures (Fig. 4). In thin section diopside is the abundant silicate, but minor amounts of garnet, quartz, feldspar, sphene, sericite and epidote are also present. Fractures of the rock indicate that there has been post-metamorphic deformation. Some of this rock shows remnants of original bedding, although in highly shattered portions the bedding is obscure.

PEGMATITES.

One of the most characteristic features of the pre-Beltian rocks exposed throughout the Ruby Range is their intimate association with pegmatites. The rocks of the Cherry Creek series at the Crystal Graphite mine have been "injected" by quartz and feldspar, so that the rocks now have a gneissic appearance. Much of the injected material is massive enough to be called pegmatitic. All pegmatites are conformable in that they follow the regional foliation and bedding. They are commonly bound by narrow selvages of mafic constituents (Fig. 5). The pegmatites are not large. They vary in thickness from a few inches to several feet and are seldom greater than one hundred feet in length. All pegmatites consist of the same characteristic assemblage of minerals. They contain quartz, orthoclase, microcline, plagioclase, biotite, garnet and graphite. Small amounts of sericite, chlorite, and epidote are present. On fresh outcrop surfaces, euhedral crystals of magnetite and the characteristic radial patterns of sillimanite clusters are noticeable.

E. N. Heinrich (3), as previously noted, classified the pegmatites intruding the Cherry Creek series at the Crystal Graphite mine as (1) pre-Beltian pegmatites, now largely metamorphosed to granulites, and (2) pegmatites of Laramide age which were commonly massive with minor aplites. Heinrich believed carbon, that formed graphite, was a primary constituent of the Lara-

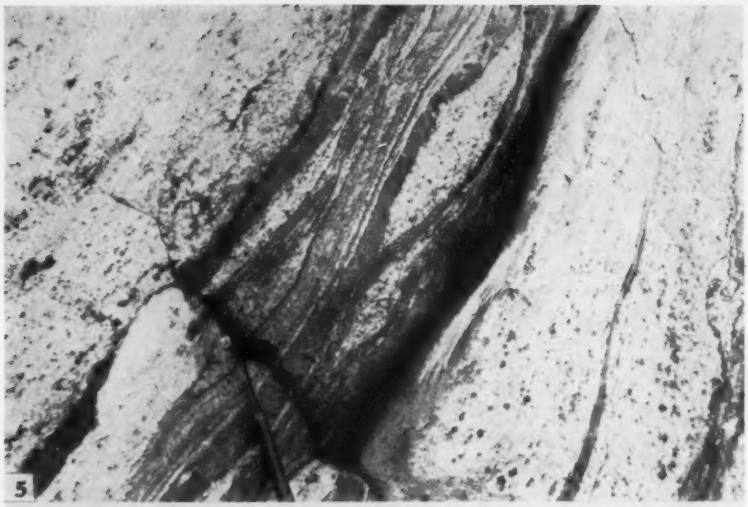


FIG. 5 (upper). Pegmatite associated with biotite-garnet gneiss. Note border selvage of mafic minerals.

FIG. 6 (lower). Granulitic fabric of pegmatite showing orientation of quartz spindles.

mide pegmatitic magma. The writer hopes to show that the pegmatites of the Crystal Graphite mine are of a single age and that these pegmatites are not genetically related to the graphite mineralization.

The most characteristic feature of the pegmatites is the orientation of their constituent minerals, i.e., the tendency for crystals of the same mineral to assume parallel or subparallel crystallographic orientation. This well foliated fabric in many of the pegmatites is due partly to parallel orientation of mica flakes and partly to the occurrence of quartz in parallel bands or streaks. The bands and streaks are actually quartz spindles occurring in coarse to fine discontinuous parallel layers (Fig. 6). This granulitic fabric was first observed in the field as characterizing the more foliated pegmatites, but later the same fabric was found to be responsible for a less distinct banding in those pegmatites formerly mapped as massive. Many pegmatites can be seen grading from a granulitic fabric to a more massive fabric with less distinct banding.

A pegmatite lying about 300 feet southeast of the marble nose is well exposed in the most westwardly prospect pit of the Lucky Boy Claim. It is herein described as characteristic of those pegmatites that grade from a well foliated to an apparently massive fabric. The pegmatite is conformable to the regional foliation. It can be traced around the nose of the fold by means of scattered outcrops and float. The pegmatite is bordered on the east side by biotite-garnet gneiss, and grades westward from foliated to massive to aplitic pegmatite. Samples across this pegmatite show no mineralogical change. The easternmost phase is highly sheared parallel to the foliation, with graphite forming parallel flakes. Thin sections show granulation along the boundaries of these sheared zones. Inward from the border the fabric is that of the typical granulitic facies, with parallel orientation of quartz spindles and mica. The west border of the pegmatite is more massive and coarsely crystalline but does show some evidence of the granulitic fabric. Aplitic textures are developed in the latter phase.

The pegmatite of the Birds Nest workings, 3,500 feet northeast of the main workings, exhibits the same granulitic fabric as those pegmatites about the main workings. It is conformable with the bedding of the marble and is about twenty feet thick.

It is difficult to distinguish between the igneous and metamorphic elements in the granulitic fabric of such rocks. Whether the granulitic fabric of the pegmatites was developed during magmatic flow prior to complete solidification of the pegmatites, or whether it is due to acute deformation along fold axes, synchronous with regional metamorphism, is not clear.

OCCURRENCE OF GRAPHITE.

The occurrence of vein-type graphite in combination with disseminated graphite at the Crystal Graphite deposits has prompted Bastin (2) to compare the deposits to those of Ceylon.

The vein-type graphite, as noted by Armstrong and Full (1), is best developed about the nose of the fold and occupies fissures mostly discordant to regional foliation. Vein-type graphite also occurs bordering pegmatites in

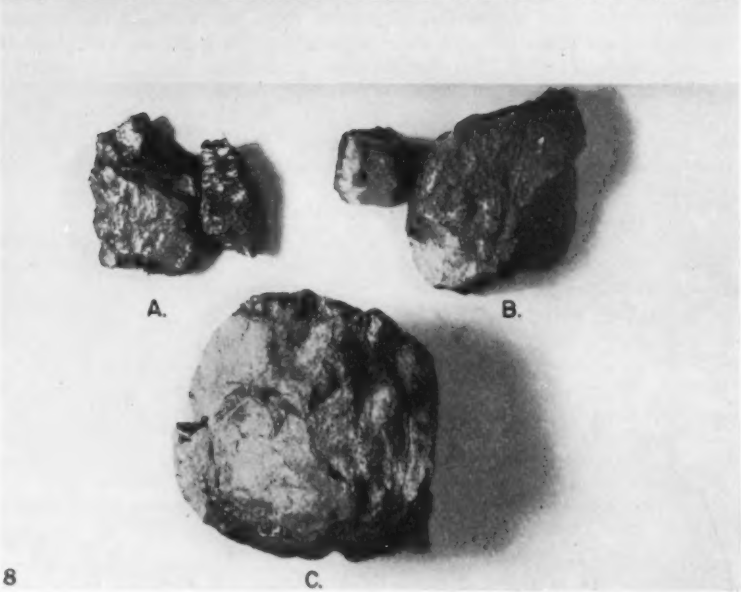


FIG. 7 (upper). Graphite along fracture in pegmatite with development of slickensides.

FIG. 8 (lower). a) Comb type graphite from small fracture fillings; b) Graphite coating vein breccia; c) Rosette type graphite developed in shattered lime silicate rock.

many places. The veins seen by the writer vary from less than ⅛ inch to over two feet in width. They consist of irregular patches and networks of flake graphite. The walls of the veins are commonly sharp, and included minerals are absent; however, fragments of the wall rocks occur imbedded in the graphite and might easily be mistaken for gangue minerals (Fig. 8b). Surface alteration has masked much of the character of the larger veins and has produced a limonitic stain or film on some of the graphite. The graphite in veins forms comb structures composed of parallel platy needles and rosettes of platy needles of irregular orientation. Massive and streaky graphite is also present in places and is characterized by slickensides that are probably produced by post-graphite movement (Fig. 7). Pegmatite cut by graphite veinlets shows no alteration. Microscopic examination shows no introduced material in pegmatite other than graphite. Granulation is found in pegmatite bordering all such fractures. Open cavities, crustification, and comb structures that occur in the veins are all features of the kinds found in typical epithermal deposits.

Disseminated flake graphite is not restricted to any stratigraphic horizon within the country rock. Examination of the workings indicates a corollary between the abundance of the disseminated flake graphite and the development of fissure veins. The flake graphite is generally arranged in the gneiss parallel to the foliation. Granulation or micro-fractures follow such seams. Much graphite also surrounds anhedra of garnet where structural deformation, following development of the garnet, was perhaps greater.

Heinrich (3) concluded that the deposition of graphite in micro-fractures has been accompanied by late quartz and albite. The author has examined such "veinlets" and found that they consist of graphite replacing granulated quartz-albite material forming the walls of fractures. No change in the anorthite content of the included granulated material and that of the surrounding rock was found, however.

All evidence shows that the movement, or at least the deposition of the graphite, must have occurred after the development of the pegmatites and after the period of metamorphism. It is nowhere enclosed by, and is always later than, any mineral directly attributed to the metamorphic or igneous facies.

CONTROL OF GRAPHITE BY STRUCTURE.

The attitude of bedding has had an influence on the loci of disseminated graphite and to some extent has controlled the vein type ore. The disseminated material tends to follow the strike of the bedding on the limbs of the fold. Fracturing has developed about the nose of the fold where the dip of the bedding is less steep and probably perpendicular to the deforming force. This zone of fracture, controlling the development of the Ceylon type graphite, emphasized by Armstrong and Full (1) can be traced by mine workings as roughly paralleling the plunge of the marble fold. The greater competency of the pegmatites is expressed on the limbs of the folds where fractures developed within them are oblique to the bedding of the country rock. The attitude of the bedding, relative to shearing forces, has not been the only control-

ling feature. An important factor is the planes of weakness paralleling the margins of pegmatites. The latter is well exemplified at the Lucky Boy prospect pit. The easternmost margin of this pegmatite is subjected to shearing and granulation affording structural control for the development of graphite. It was probably this phenomenon that first led Bastin (2) to emphasize the relationship between graphite and pegmatites.

ORIGIN OF THE GRAPHITE.

The refractory nature of graphite is well known and many writers have speculated on its ultimate source and method of transportation. The relative merits of various hypotheses on origin of the graphite at the Crystal Graphite mine have been ably discussed by Winchell (4, 5) and Bastin (2). Winchell, as mentioned earlier, concluded that the graphite of the pegmatite and veins before deposition must have existed in the solutions as some compound of carbon. It was argued that the most probable forms of these solutions were oxides of carbon or hydrocarbons. Winchell pointed out that while the equilibrium of CO and CO_2 changed with varying temperatures, the end result, when these solutions cooled below 500° C, was as indicated by the following equations:

$$2CO + 2H_2O \rightarrow 2CO_2 + 2H_2$$
$$CO_2 + 2H_2 \rightarrow C + 2H_2O$$

Winchell believes that the existence of these gases in solution with the magma cannot be debated as they are important constituents of volcanic emanations. He further states that when magmas containing any abnormally large amount of CO_2, CO, and H_2 solidify at a depth so great that the gases cannot escape, graphite deposits are to be expected.

Bastin does not believe that it has been shown that carbon cannot exist in igneous magmas in the elemental form. He further states that the fact that graphite volatilizes only at high temperatures under ordinary atmospheric conditions forms no valid argument against its existence in the elemental form in a rock magma at much lower temperatures. Bastin believes that carbon disseminated in sedimentary beds would furnish an adequate source for the graphite that has been discovered in the region. The mobilization and subsequent deposition of the graphite by a granitic magma which invaded the sediments is considered by Bastin to be the most probable origin.

Irrespective of the source of the graphite, any theory on origin must fit the following facts:

1. The graphite is younger than any period of regional metamorphism or igneous intrusion.
2. Graphite mineralization has been controlled by microfractures, granulation, and fissure openings.
3. There are no associated gangue minerals or alteration products.
4. Texture and structure of the vein type graphite are typical of low pressure, near-surface mineral deposits.

CONCLUSION.

It seems highly improbable that the combination of vein type graphite and disseminated flake graphite would require two separate and incongruous explanations when the fractures controlling vein type graphite and disseminated flake graphite are closely associated. This structural control of graphite mineralization is emphasized in all the rock types. The mineralization is confined to late fractures and shears devoid of associated gangue or introduced minerals. These fractures are accompanied by graphite mineralization typical of open vein fillings (Fig. 4). There is no indication of any pre-metamorphic graphite associated with or included by minerals of metamorphic or igneous facies.

The graphite mineralization at the Crystal Graphite mine has the texture and structural features of those deposits typical of low pressure, near-surface epithermal mineral deposits.

It must be concluded, therefore, that the explanation for such an occurrence must be one of two possibilities. Either metamorphism has converted indigenous carbonaceous matter into graphite and caused mobilization of some of it, or the graphite is epigenetic in origin, having been deposited from gaseous emanations of carbon or hydrocarbons.

CRYSTAL FALLS, MICHIGAN,
July 17, 1953.

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GEOLOGY AND ORE DEPOSITS OF BAJA CALIFORNIA, MEXICO.

EDWARD WISSER.

ABSTRACT.

The geologic record in Baja California probably begins with the Upper Jurassic. A series of slates, quartzites, cherts and metavolcanics strongly suggestive of the California Franciscan is exposed along the western coast. The Franciscan (?) rocks were deposited in a synclinal trough that was probably an extension of the Californian Franciscan trough. In the Lower Cretaceous this series was isoclinally folded and resulting land submerged to received a sea that also occupied a narrow geosynclinal trough, the axis of which lay east of the earlier one. Here were laid down shales, sandstones, conglomerates and interbedded volcanics. Major diastrophism abruptly ended this period of sedimentation in the Mid-Cretaceous; Cretaceous and older beds were intensely folded along north-northwest axes; the Baja California composite batholith invaded the folded rocks, and intrusion was followed by formation of tungsten, iron, copper, manganese and gold deposits.

This orogenic cycle closely resembles the Nevadan cycle in California except in one particular: the Sierra Nevada batholith carries a major gold belt along its western border, but only unimportant, scattered gold deposits accompany the Baja California batholith.

In Upper Cretaceous and early Tertiary time the west flanks of the peninsula were recurrently submerged. In the Upper Miocene an elongated uplift occupied the site of the present gulf, and a thick series of volcanics poured out from fissures along its crest. Uplift continued in the Pliocene, but the whaleback was broken by a zone of great faults along its western crest, corresponding to the east coast of the present peninsula. The crestal portion of the uplift dropped as a half-graben, the free side swinging down like a trapdoor along the major faults, to form the present Gulf of California.

Evolution of the Gulf with its western frame, the peninsula of Baja California, bears striking resemblance to that of the Great Basin and its western frame, the Sierra Nevada.

Probably at some time during the Tertiary the silver-gold-base metal deposits of El Triunfo formed along a thrust fault. In the Pliocene, probably just before the major faulting along the eastern border of the peninsula, hypogene copper and manganese solutions rose along fissures which, with the later major faults, were probably localized by the steep eastern wall of the Baja California batholith. In places the fissures broke through the floor of the shallow sea and deposited copper and manganese syngenetically with tuff falling into the sea by explosive volcanism. The great Boleo copper deposits were formed in that manner, but important manganese ore bodies are epigenetic, deposited by hydrothermal solutions in preexisting rocks.

INTRODUCTION.

LITTLE-KNOWN regions challenge interest, deservedly or not. Baja California, excepting the strip adjoining the United States, seems to be more or less a

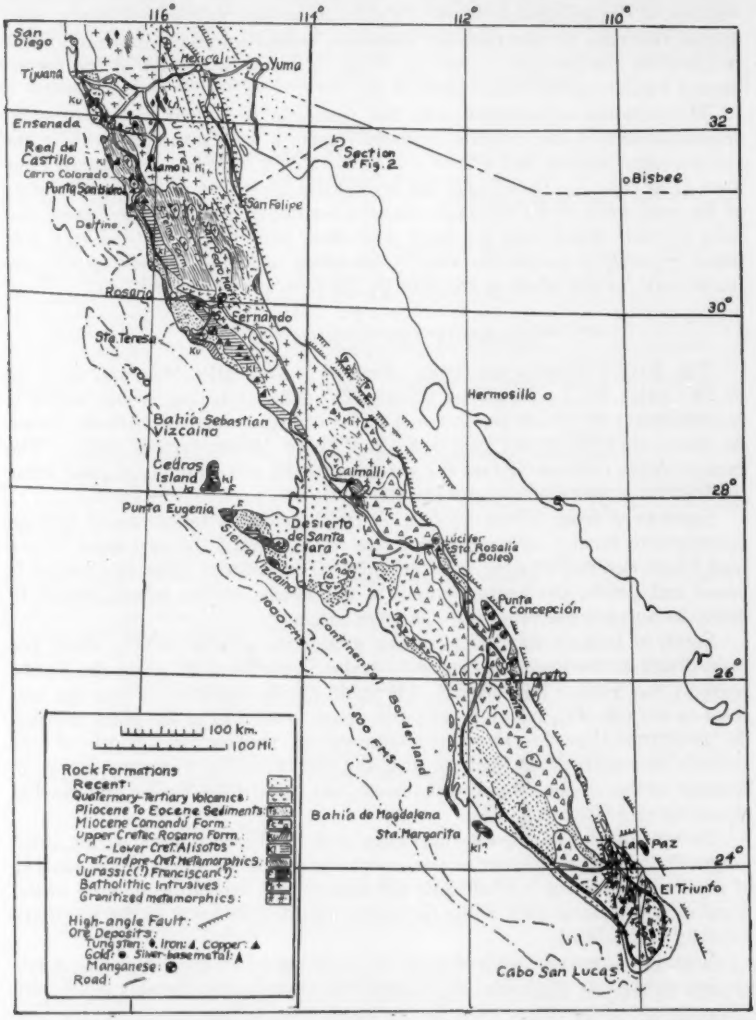

FIG. 1. Sketch geological map of Baja California. Based on (4, Plate 1); on P. B. King: Carta geológica de la parte septentrional de la República Mexicana; on field work by L. B. Wright and E. Wisser, and on private data.

terra incognita to many geologists. This paper attempts to outline the salient features of the geology of the Baja California region, to trace its history with special reference to diastrophism, intrusion, volcanism and metallization, and to correlate the geologic history of Baja California with that of the better-known Pacific coastal region north of it.

My personal aquaintance with the peninsula is limited to a few weeks reconnaissance in the extreme southern region, a week's similar work in the north-central portion, and a brief visit to the Sierra Vizcaino or Western Cape area (Fig. 1). L. B. Wright has generously placed at my disposal results of his field work in the extreme southern region, covering a larger area, and done in more detail than my brief stay there permitted. For the rest, this paper is purely a compilation from publications and unpublished reports; the framework for the whole is supplied by the monograph of Beal (4).[1]

GEOGRAPHY AND GEOMORPHOLOGY.

The Baja California peninsula (Fig. 1) is 760 miles long and from 30 to 150 miles wide. North of latitude 28°–30′ nearly the whole width is mountainous; the divide lies just east of the center, coinciding with the Sierra de Juárez and the higher Sierra de San Pedro Mártir farther south. The eastern slopes of these Sierras are abrupt, straight and mutually aligned while the western slopes are long and gentle.

Southward from Sierra de San Pedro Mártir the mountainous terrane converges to form a narrower spine that veers toward the east coast where high bluffs descend straight into the Gulf. The western slope in contrast is broad and gentle, descending evenly to the Pacific except where broken in places by subordinate ranges of moderate height.

South of latitude 28° the peninsula attains its greatest width, where the main divide on the east is separated from the Sierra Vizcaino along the Pacific coast by the Santa Clara desert. The main divide continues to hug the east coast to latitude 25°, where it starts its descent toward the flat plain crossing the peninsula from La Paz Bay southwest to the Pacific. South of this isthmus the country rises again to form the Sierra de Victoria, whose crest, in contrast to that of the ranges to the north, lies toward the Pacific and reaches elevations of 5,000 feet.

Except for the northwestern portion and the highest parts of the main ranges Baja California is one of the dryest regions of the world. The density of population is about 3 inhabitants per square mile, but since the bulk of the population is concentrated in the far north, considerable areas to the south are virtually uninhabited.

Outside of several hundred miles of paved road in the far north, roads are few and mostly execrable; air transport however is considerably developed.

OUTLINE OF GEOLOGY.

Dominating the geology of Baja California is the great batholith, which extends 1000 miles, from near Riverside, California, down the backbone of

[1] Numbers in parentheses refer to Bibliography at end of paper.

the peninsula to its southern tip, although covered in places by younger rocks (Fig. 1). As Larsen shows (36, p. 1) the batholith was emplaced by many separate injections that range in composition from gabbro to granite, although the dominant rock type is quartz diorite. Roof pendants and septa of metasediments and metavolcanics are large and abundant.

TABLE 1.

STRATIGRAPHIC SECTION, BAJA CALIFORNIA.

Unconformity: x x x x x

Epoch	European nomenclature (Cretaceous)	Formation, description	Thickness
Recent Pleistocene*		Alluvium, dunes, etc. Lake beds, alluvial fans, etc.	
		x x x x x x x x x x x x x x x x x x x x	
Quaternary- Tertiary		Undifferentiated basalt, andesite, etc. flows, pyroclastics, intrusions	0–300′
		x x x x x x x x x x x x x x x x x x x x	
Pliocene*		Salada. Marine sandstones, shales	20–2000′
		x x x x x x x x x x x x x x x x x x x x	
Miocene Upper		Comondú. Andesite, basalt, rhyolite flows, tuffs, agglomerates, grading westward to conglomerate, sandstones	500–4000′
Middle			
		x x x x x x x x x x x x x x x x x x x x	
Lower		San Isidro. Marine sandstone, shale	700–2500′
		x x x x x x x x x x x x x x x x x x x x	
Oligocene Upper		San Gregorio. Shale	500′ plus
		x x x x x x x x x x x x x x x x x x x x	
Eocene Upper Middle		Tepetate. Silts, sandstones	50–4000′
		x x x x x x x x x x x x x x x x x x x x	
Cretaceous Upper	Danian		
	Maestrichtian Senonian	Rosario. Brown marine sandstones, dark shales. Conglomerate at base	2500′ plus
	Turonian	x x x x x x x x x x x x x x x x x x x x	
	Cenomanian	Alisitos. Sandstone, shale, conglomerate, interbedded volcanics	500′ plus
Cretaceous Lower	Albian		
	Aptian Neocomian		
		x x x x x x x x x x x x x x x x x x x x	
Jurassic?		Franciscan (?). Quartzite, chert, slate, metavolcanics, etc.	Great

* For Plio-Pleistocene of Santa Rosalía area see Table 2.

Northern Area (U. S. Border to Lat. 28°).—In California the batholith intrudes on the east highly folded schists and quartzites, in part at least of Mississippian age (36, p. 1). South of the border the Sierra de Juárez in the medial portion of the batholith exhibits roof pendants of strongly folded metasediments "probably of late Paleozoic age," surrounded by an intrusive complex of quartz diorite, diorite and abundant pegmatite dikes (22, p. 77–78).

In California the batholith intrudes, on the west, Triassic sediments and

Jurassic (?) volcanics (36, p. 1). South of the border the western edge of the batholith is concealed by post-batholith rocks as far south as the latitude of Ensenada; from there nearly to the Santa Clara desert batholithic rocks intrude the San Fernando formation of Beal (4, p. 38–40) which correlates with the Alisitos formation of Santillán and Berrera (47) and is shown under the latter name in Figure 1.

The Alisitos consists of shale, sandstone, limestone and conglomerate abundantly interbedded with pyroclastics, flows and possibly sills, all of intermediate to basic composition. The whole series is as a rule strongly folded, and in many places metamorphosed to slate, quartzite, marble, meta-tuff, or greenstone.

Kirk and MacIntyre (33) assign a Cenomanian age to the Alisitos, on the basis of fossils collected near Punta San Isidro below Ensenada (Table 1). Durham (13) states that part of the Alisitos is Albian.

In the Sierra de San Pedro Mártir, east of the belt of Alisitos studied by Kirk and MacIntyre, quartz diorite, granodiorite and granite intrude highly

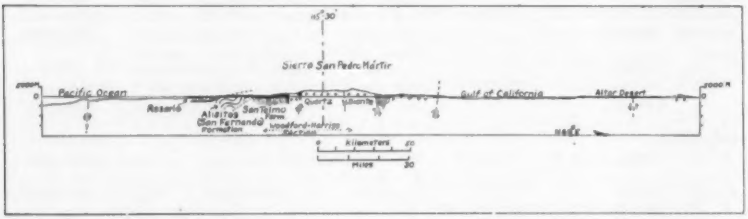

FIG. 2. Diagrammatic vertical section through Sierra de San Pedro Mártir. Based on Beal (4, Plate 1, Section A-B) and on Woodford and Harriss (60, Plate 7, Map and Section A-A′).

folded metasediments and metavolcanics, the San Telmo formation of Woodford and Harriss (60, p. 1306–1310). The San Telmo consists mainly of slate, phyllite, marble, metaconglomerate and metavolcanics, but shows in places nearly fresh limestone and shale containing corals and echinoids "which have a Mesozoic aspect" (60, p. 1307). As Beal suggests (4, p. 39) the San Telmo may represent a more highly metamorphosed facies of the Alisitos; if so, it may also contain Lower Cretaceous rocks older than Albian.

Figures 1 and 2 show the spatial relation of the San Telmo to the Alisitos exposures.

West of the Alisitos belt and exposed mainly along the Pacific coast north of latitude 29° is a series of marine sandstones and shales called by Beal the Rosario formation (4, p. 40). On the basis of fossils collected near Punta San Isidro the Rosario is assigned to the Maestrichtian (33; Table 1), but according to Durham (13) lower exposed horizons are probably Senonian.

The Rosario, with a heavy basal conglomerate, lies with gentle westward dip upon a nearly flat surface truncating the highly folded Alisitos beds. Unlike the Alisitos, the Rosario shows no signs of having suffered intrusion.

Above the Rosario lie, with slight angular but considerable erosional unconformity, Eocene silts and sandstones (Tepetate formation, Table 1). These overlap from the Rosario formation onto the granitic rocks of the batholith (4, p. 44–51).

The structure of the Northern area is reflected in the geomorphology. A basement of plutonic and metamorphic crystalline rocks and strongly folded Alisitos sediments and volcanics has been partly peneplained, covered, toward the west coast, by unfolded Rosario and Tepetate sediments, and the whole deformed as a block, which was down-tilted or down-warped on the west, up-tilted or up-warped on the east, where the highest part of the uplift is abruptly truncated by great high-angle faults with downthrow on the east, toward the Gulf. The resemblance to the Sierra Nevada is striking.

The warped or tilted crystalline block persists southward to latitude 28°, where it passes under Miocene volcanics (Fig. 1).

Western Cape Area (Lat. 28° to Lat. 27°).—Here the peninsula expands abruptly westward to Punta Eugenia, exposing a Pacific coastal range radically different in some respects from the main Peninsular range on the east. The Sierra Vizcaino, the main portion of this range, consists of a basement of diorite, granite and serpentine together with small exposures of a rock series containing quartzite, chert, limestone and metavolcanics which may be Franciscan in age (4, p. 36). The basement complex is overlain by Cretaceous (?) conglomerate, sandstone and shale and by Eocene Tepetate sediments.

Highly mountainous Cedros Island lies along the northwest prolongation of the Sierra Vizcaino and smaller islands are strung along the same axis farther northwest.

Cedros and the other islands not only form the northwestern physiographic prolongation of the Sierra Vizcaino, suggesting recent submergence of a once continuous mountain range: they prolong to the northwest the Sierra Vizcaino basement rocks as well. Thus Cedros Island shows in its southern portion, according to Hanna (25), a basement of contorted, nearly vertical cherts, slates etc., stratigraphically overlain by a thick series of shales, Cenomanian or older in age. Veatch (54, p. 144) observed intrusion of serpentine with associated chromite in the metamorphic series. Hutchins (28), exploring Cedros Island for chromite in World War II on the strength of Veatch's report of 83 years before, concluded that the Cedros chromite deposits resembled greatly those of the California Coast Ranges, and, like the latter deposits, offered no promise for large-scale exploitation.

Several small islands northwest of Cedros expose chert resembling that of the Franciscan in California, and Beal (4, p. 107–108) and others regard the belt of metamorphics along the western edge of Baja California as correlative in age and lithology with the Franciscan of California.

The peninsular divide in the Western Cape area continues to hug the Gulf coast, which here as elsewhere is the locus of major faulting with downthrow on the east (Fig. 1). The Miocene Comondú formation covers most of the divide here, extending well down the gentle westward slope. The Comondú along the Gulf coast and on the divide consists of a thick series of basaltic,

andesitic and rhyolitic flows, tuffs and agglomerates. Down the western slope these wedge to alluvial conglomerates which in turn grade to sandstone farther west (23, p. 634; 4, p. 74–77; 57, p. 1770–1773; 1, p. 11–12; 55, p. 575).

Along the low coastal strip below the great bluffs overlooking the Gulf between Santa Rosalia and Punta Concepción Pliocene and Pleistocene tuffs, conglomerates, sandstones and limestones unconformably overlie Comondú volcanics step-faulted down to the east (57, p. 1767).

South-Central Area (Lat. 27° to Lat. 24°–15′).—The Gulf coastal belt of Plio-Pleistocene sediments and tuffs persists southward past Loreto, where the Comondú volcanics cut out the belt (Fig. 1). The Comondú formation, grading to sandstone down the west slope of the divide, is bordered on the west by Lower Miocene to Eocene marine shales and sandstones, these in turn being overlapped toward the Pacific coast by the Pliocene sandstones and limestones of the Salada formation.

The far western belt of Franciscan (?) exposed on Cedros Island and in the Sierra Vizcaino seems to persist southeast as far as the mouth of Magdalena Bay, where metamorphic and ultrabasic rocks are exposed.

Southern Cape Area (South of Lat. 24°–15′ N).—The following description is based on data collected by L. B. Wright and myself and hitherto unpublished.

The Sierra de Victoria, which dominates the Southern Cape area, resembles the Sierra de San Pedro Mártir in several respects. Both are upfaulted blocks of crystalline rocks; each block exhibits diorite, granodiorite and granite invading highly metamorphosed sediments, originally shale, sandstone, limestone and conglomerate but now altered to biotite schist, quartzite, quartz-biotite schist, quartz-sericite schist, marble and metaconglomerate. In each area injection gneisses showing relict sedimentary texture grade by granitization to holocrystalline massives.

The two blocks differ, however, in structure. In the Sierra San Pedro Mártir the metamorphics are closely folded along northwest axes, while in the Sierra de Victoria they are gently folded, the major fold being a broad north-south syncline whose axis coincides with the 110th meridian, and which plunges gently north. The two north-south granite prongs shown in Figure 1 are believed by Wright to be outcrops of a sill-like body downfolded in the syncline. Since it is unlikely that solidified granite would fold in this manner, it is probable that the granite "sill" formed by selective migmatization of sediments already folded.

GEOLOGIC HISTORY.

Pre-Cretaceous.—Figure 3B modifies Eardley's paleotectonic map of the late Jurassic (15, Plate 13) by extending the California trough from where Eardley abandons it off the coast of southern California southward. The extension includes the Franciscan (?) on Cedros Island, in the Sierra Vizcaino and at the mouth of Magdalena Bay, where Hirschi and De Quervain (26) describe a peridotite intrusion, and where Santa Margarita Island was considered by Lindgren after study of rock specimens to consist of crystalline schists with talc and serpentine (39, p. 25).

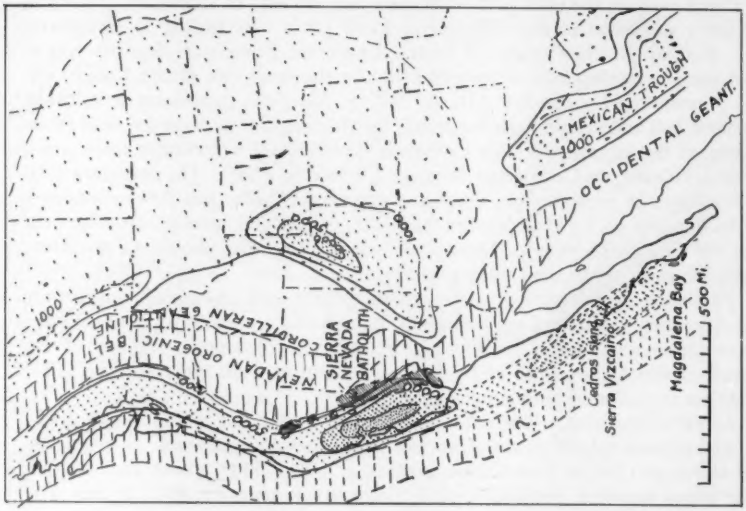

FIG. 3B. Tectonic map of Late Jurassic. Based on Eardley (15, Plate 13).

FIG. 3A. Tectonic map of Early and Middle Jurassic. Based on Eardley (15, Plate 12).

Beal (4, p. 107–108) assigns the source of the Franciscan (?) sediments to a land mass on the east, part of the Juro-Sonora land of Crickmay (12) or a southern extension of the Mohavia of Reed (46). According to Taliaferro (52, p. 124) the chief source of central California Franciscan deposits was a land mass or archipelago of rugged relief on the west side of the trough, off the present coast. Eardley (16, p. 312, p. 334–342) postulates a volcanic orogenic belt and archipelago bordering the California trough on the west from Alaska to the latitudes of Baja California, present and tectonically active continuously from pre-Ordovician through Cretaceous time. He considers this archipelago the source of the abundant graywacke, tuffs, and flows contained in the deposits of the trough over this long period. He stresses also the fact that the California trough deposits are typically metamorphosed to phyllites, argillites, slate, schist, and metavolcanics.

Persistence southward of such a characteristic rock assemblage suggests a corresponding southward persistence of the volcanic archipelago, in which case the major source of the Baja California Franciscan (?) deposits lay west of the trough in which they were laid down. The continent on the east (Fig. 3B) doubtless contributed sediments also.

Lower Cretaceous.—The date of the orogeny recorded by the intense folding and metamorphism of the Franciscan (?) rocks is unknown. The cherts and slates on Cedros Island were isoclinally folded, lifted above the sea and their edges bevelled, probably before Cenomanian time (p. 49); if they are Upper Jurassic in age, they could have been folded at any time between uppermost Jurassic and uppermost Lower Cretaceous.

The extent of this Lower Cretaceous (?) orogeny is likewise unknown. The Nevadan revolution in California resulted in a pushing of the California trough westward by a westward expansion of the Cordilleran geanticline (Figs. 3A, B). In the Baja California region, the axis of the trough that succeeded the Franciscan (?) trough after the Lower Cretaceous (?) orogeny lay east of the axis of the Franciscan (?) trough (compare Figs. 3B and 4A). If the analogy holds, the Baja California Lower Cretaceous diastrophism originated on the west, within the volcanic archipelago.

Ultrabasic intrusions represented by serpentine on Cedros Island and elsewhere accompanied or closely followed the Lower Cretaceous (?) orogeny. Granitic rocks occur on Cedros Island, in the Sierra Vizcaino and elsewhere along the far western belt; but whether the granite was intruded during the Lower Cretaceous (?) orogeny or during the Mid-Cretaceous orogeny is not clear. According to Beal (4, p. 36) the granite in the Sierra Vizcaino is intruded by serpentine. In a given orogenic-intrusive cycle ultrabasic usually precede more acidic intrusions, suggesting that the Sierra Vizcaino granite belongs to a cycle older than that of the serpentine. On the other hand the granite might be associated with the Lower Cretaceous (?) orogeny and the serpentine might represent an early, western phase of the Mid-Cretaceous orogeny that culminated farther east in the intrusion of the Baja California batholith.

After the Mid-Cretaceous (?) orogeny the resulting land mass was base-levelled and submerged beneath a sea which spread probably farther east than

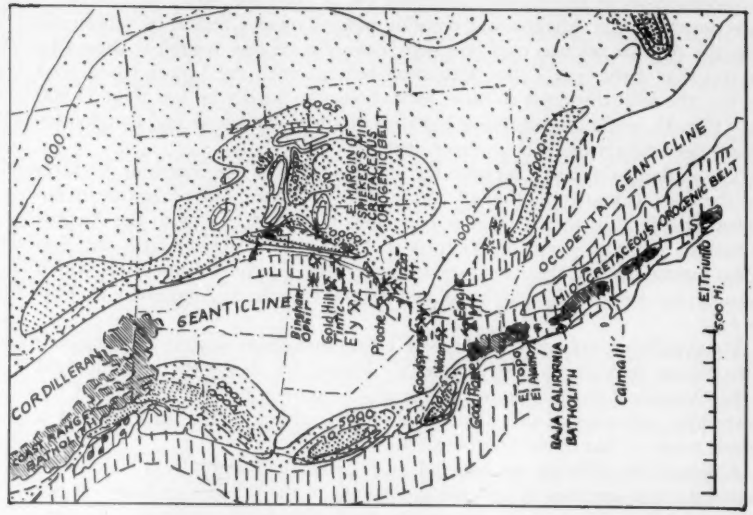

FIG. 4B. Tectonic map of Upper Cretaceous. Based on Eardley (15, Plate 16).

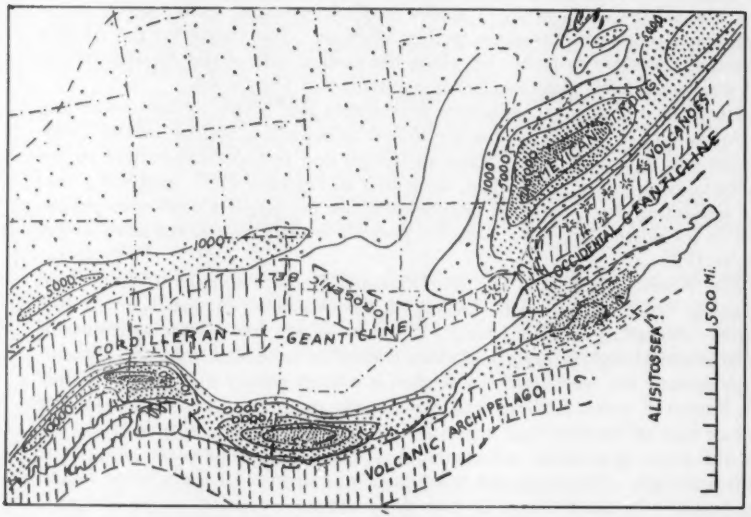

FIG. 4A. Tectonic map of Lower Cretaceous. Based on Eardley (15, Plate 15).

did the Franciscan (?) sea. This later sea covered at least the western portion and probably all of the present peninsula (4, p. 108; Fig. 4A), and within it were deposited the Alisitos and possibly older Lower Cretaceous sediments. That the Alisitos sea was part of a geosynclinally sagging trough is shown by the fact that if the San Telmo formation belongs with the Lower Cretaceous (p. 48) the total thickness of these formations can hardly be less than 15,000 feet (Fig. 2), while the recurring horizons of shale, sandstone and conglomerate are persistently of shallow-water origin.

The striking similarity between the metamorphics of the Sierra de Victoria and the San Telmo formation of Sierra de San Pedro Mártir has been described (p. 50). If the San Telmo correlates in part at least with the Alisitos formation, and the Sierra de Victoria metamorphics correlate with the San Telmo metamorphics, the Alisitos sea covered the Southern Cape area, which probably lay toward the southeast end of the trough, as suggested in Figure 4A.

Metavolcanics, abundant in the San Telmo formation, appear to be lacking in the Sierra de Victoria metamorphics. Figure 4A shows the volcanic field on the Occidental geanticline, which, as will be shown, probably furnished the interbedded volcanics of the Alisitos formation, ending to the south-east at a latitude north of that of the Southern Cape area.

Although the Alisitos sea covered most or all of present Baja California, recurring conglomerates and coarse sandstones in the Alisitos exposed on the peninsula reflect the presence of nearby land periodically uplifted. In contrast, the thick Cenomanian(?) shales on Cedros Island seem free of coarse clastics and represent deposition farther offshore. The source for the Alisitos sediments therefore probably lay along the eastern side of the Alisitos trough and was presumably the Occidental geanticline of Figure 4A.

However, the Alisitos sediments near Punta San Isidro contain, according to Durham (13), a coral-rudistid-echinoid fauna characteristic of the Cenomanian and Albanian of the Mexican trough and unknown elsewhere in the Pacific coastal region. This fact, according to Durham (13), suggests a seaway separating the Occidental geanticline from the larger Cordilleran geanticline on the north (Fig. 4A). Such a possible seaway was hinted at by Imlay (29, p. 1739).

The Alisitos sediments on the Peninsula contain abundant interbedded volcanics, which appear to be lacking in the Alisitos (?) shales on Cedros Island. According to R. E. King (32, p. 1677) marine Albian sediments of the Mexican trough in eastern Sonora contain interbedded volcanics that increase toward the west until the section is almost wholly volcanic. Eardley (15, Plate 15) portrays these relations visually by a string of volcanoes along the east side of the Occidental geanticline. Probably this volcanic field covered the entire geanticline and contributed volcanics to the eastern side of the Alisitos trough. The apparent freedom from volcanics of the Cedros Island Cenomanian(?) shales suggests that the southern extension of the Volcanic archipelago had by this time foundered.

Mid-Cretaceous Orogeny.—The Alisitos(?) shales on Cedros Island dip gently west. To the east, on the Pacific slope of the Peninsula Alisitos beds

are moderately to strongly folded along north-northwest axes, parallel to the axis of the peninsula. Farther east the San Telmo beds are still more strongly folded (Figs. 1, 2). Still farther east, on the Gulf side of the batholith in the Northern area, crystalline schists of a sort not observed on the Pacific side appear (4, p. 35); these old-looking schists may represent a still more intensely folded and metamorphosed facies of the Alisitos-San Telmo series, or they may be much older.

The Alisitos formation suffered its intense folding between the Cenomanian (age of the upper Alisitos) and the Senonian (age of the lower exposures of the virtually unfolded Rosario formation). The region in which the Alisitos beds now exposed on the peninsula were laid down was uplifted, profoundly eroded and its western portion submerged before the Rosario beds were laid down, processes which must have consumed considerable time. Schuchert (48, p. 35) quotes Boese and Wittich (7) as considering the core of the Peninsular range to contain Middle Cretaceous sediments folded and intruded in late Turonian time (early Upper Cretaceous).

Direct evidence is lacking for dating the folding in the metamorphic rocks of unknown age in the batholithic belt of Baja California, but the strict accordance of folds in these rocks with those in the Alisitos, the universal northwest trend of all the fold axes, suggests a single period of major folding, i.e., in the Mid-Cretaceous.

The regional fold pattern persists northward into California, where the Paleozoic metasediments on the east and the Triassic sediments and Jurassic(?) volcanics on the west are all sharply folded along northwest axes, with isoclinal dip to the east (36, p. 121). There was clearly only one period of major folding here, and that period may be placed with some confidence in the Mid-Cretaceous.

Mid-Cretaceous Orogeny of Western North America.—The Mid-Cretaceous orogenic belt in the Baja California region is a segment of a much more extensive belt associated with the Cordilleran-Occidental geanticline (Fig. 4B). This persistent elongated land mass from the Jurassic (or earlier) through the Cretaceous separated Pacific geosynclinal troughs, with their volcanic rock assemblages, from interior troughs, much more free from volcanic detritus (Fig. 3B, 4A, 4B).

The geanticline was not merely a passive rib between two sagging troughs, for during the Nevadan revolution its western edge jumped westward, uplifting the sediments and volcanics that had been deposited in the California trough, folding them isoclinally and forming a new trough farther west by destroying the old one on the east (Figs. 3A, 3B).

Again in the Lower Cretaceous an edge of the geanticline became the site of marked diastrophism, but this time it was the eastern edge (Fig. 4A). Activity along this eastern belt continued during the rest of Cretaceous time and culminated in the Laramide revolution; but, as Spieker (51) and others show, at least one of the earlier orogenic disturbances was important and widespread. Since it took place "near the beginning of the Upper Cretaceous" (51, p. 150) Spieker has named this disturbance the Mid-Cretaceous orogeny.

The eastern limit of this orogenic belt in the area studied by Spieker is shown in Figure 4B.

Eardley's paleotectonic map for the Upper Cretaceous (15, Plate 16, on which Fig. 4B is based) extends Spieker's orogenic belt southward. According to Eardley the belt crosses from the eastern to the western margin of the geanticline about where the seaway is supposed to have cut through the geanticlinal spine in the Lower Cretaceous (Fig. 4A). As Figure 4B shows, the belt of intense folding in the Baja California region forms the southern segment of this Mid-Cretaceous orogenic belt.

Intrusion of the Baja California Batholith.—Closely following the folding, and probably while the uplift accompanying it was still active, came the intrusion of the batholith. Larsen (36, p. 171) shows that the major folding and metamorphism took place before the earliest batholithic intrusion, that of gabbro.

According to Larsen, a primary gabbroic magma emplaced itself at depth as a linear body aligned northwest parallel to the fold axes, to the axis of each successive intrusion given off by the parent magma as the latter differentiated, to the strike of post-batholith sedimentary formations and faults, to the trend of the mountain ranges, and finally, parallel to the trend of the present peninsula (36, p. 119). One might add that the northwest direction of elongation of the gabbro and later intrusions parallels also the west margin of the Occidental geanticline and, in Baja California, the axis of the Alisitos trough (Fig. 4B).

Larsen believes that movement toward the surface of the successively differentiated fractions of the primary magma was triggered by recurrent diastrophism. Since this diastrophism produced no additional folding of the invaded rocks, one might hazard a guess that it took the form of fissuring and faulting along trends parallel to the axis of the orogenic belt and to that of the western margin of the Occidental geanticline.

Baja California Mid-Cretaceous Orogeny and California Nevadan Orogeny Compared.—Lindgren over 60 years ago noted the similarity between the Peninsular range in northern Baja California and the Sierra Nevada (40, p. 196). The substructure of each range is furnished by a composite batholith intruded in metasediments and metavolcanics, which before intrusion had been tightly folded, the folds being overturned to the west. The post-intrusion structure of each range is the same also, but will be discussed later.

Both in California and in the Baja California region the belt to be affected by orogeny was the site of deposition in a sinking linear trough, the Upper Jurassic (and older) California trough in California, the Lower-Upper Cretaceous Alisitos trough in Baja California (Figs. 3A, 4A). Each trough lay along the western border of the Cordilleran geanticline; each trough was a sagging furrow of crustal weakness. In California sedimentation was suddenly halted toward the close of the Jurassic (end of Kimmeridgian) by a westward jump of the geanticline, which pushed the sea which had filled the California trough westward with it (Fig. 3B). Where the trough had been, the sediments and volcanics deposited in it were sharply folded along axes parallel to the western margin of the advancing and rising geanticline and parallel to the

axis of the displaced trough. The folds were overturned westward, away from the crest of the geanticline and toward the deepest portion of the displaced trough.

In Baja California Mid-Cretaceous deposition in the Alisitos trough was halted by a sudden westward expansion of the Occidental geanticline. Strong uplift accompanied this westward jump; the Alisitos trough was wiped out, and the beds that had been laid down in it were sharply folded parallel to the western margin of the rising geanticline and to the axis of the former trough. The folds were overturned westward, down the slope of the uplift (Fig. 4B).

In California the composite Sierra Nevada batholith invaded the folded rocks shortly after the folding. Elongation of the pluton paralleled the fold axes, the axis of the displaced trough, and the trend of the western edge of the geanticline (Fig. 3B). The linear intrusion parallels also the strike of post-batholith rocks, the trend of the present range and the strike of post-batholith fault zones associated with formation of the range. The same conditions obtain in Baja California, as I have shown.

In California, at some time after presently exposed horizons of the Sierra Nevada pluton had solidified a zone of reverse faulting developed along the western margin of the massive; along this zone were deposited the Mother Lode gold quartz veins.

Here the analogy weakens, for mineralization associated in space and time with intrusion of the Baja California batholith is feeble and sporadically distributed. Among the ore deposits which seem to date approximately from the period of batholithic intrusion are the scheelite deposits of El Topo (Fig. 1; p. 66–67), magnetite-hematite deposits along the western margin of the batholith (p. 67), copper deposits in the same zone (p. 67–68), manganese-magnetite deposits in or near the iron-copper zone (p. 68) and finally gold quartz deposits of the Sierra Nevada type within the granitic rocks of the batholith (Alamo, p. 68–69) or in roof pendants (Real del Castillo, p. 68; Calmalli, p. 69).

The abundant roof pendants within the Baja California batholith together with the presence of mineable gold deposits within the plutonic massive itself in contrast to the barrenness of the core of the Sierra Nevada batholith do not bolster the notion that the scanty Baja California gold deposits represent the roots of formerly more extensive deposits now eroded away. On the contrary, the batholith has probably been eroded, on the whole to about the optimum horizon at which mesothermal deposits should be exposed.

What the Baja California batholith seems to lack and what the Sierra Nevada batholith obviously possesses in the Mother Lode is a great transgressive crustal flaw up which ore solutions might ascend. By far the most important ore districts of Baja California are those of Santa Rosalía (Boleo copper deposits) and El Triunfo (silver-gold-complex metals). Neither district contains ore deposits with the slightest genetic connection with the batholith, for their ores are much younger. In each district the deposits are associated with a major fault zone (p. 66; 70).

Pacific Coast Gold-Quartz Belt.—Lindgren pointed out that gold was the characteristic metal associated with the zone of great batholiths extending from

Baja California to Alaska, that copper was next in importance and that on the Pacific side of the batholiths lead was practically absent (4, p. 920–921).

Buddington shows that belts of schist, slate, graywacke and greenstone on the Pacific side of the Coast Range batholith in western Canada and Alaska carry gold-quartz veins and lodes of moderate to deep-seated origin, as well as deposits of copper sulphide and magnetite. East of the batholith, although gold deposits occur, silver-lead and zinc deposits, virtually missing from the western zone, are here abundant (8, p. 165–166 and 169–178).

Ferguson noted similar contrasts for the Sierra Nevada region. On the Pacific side of the batholith the chief commercial metal is gold occurring in quartz veins in metasediments and metavolcanics, while on the eastern side gold-quartz veins of similar age are sparse and most precious-metal deposits carry more silver than gold. Lead is scarce on the Pacific side and the only important lead deposits of California lie on the eastern side of the batholith.

A complete comparison with the above relations cannot be made for the Baja California batholith, for the country east of it has mainly foundered into the gulf. But the western margin resembles that of the batholiths to the north: lead is practically unknown along the western margin and the precious-metal deposits carry far more gold than silver.

There is a family resemblance between the gold-quartz lodes of Juneau, the gold-quartz veins of the Mother Lode and the gold-quartz veins of Baja California. All were formed at considerable depth; all contain sparse sulphides; all carry gold in excess of silver; all formed either in the metasediments and metavolcanics of the California or Pacific trough or not far inside the western margins of the batholiths that invaded the trough.

The trough was a long-lived belt of crustal weakness. Eardley (15, Fig. 18, p. 55) shows the coincidence of the Permian Pacific trough and the belt of Mesozoic batholiths.

Before intrusion of the batholiths the weak belt tended to be somewhat diffuse, maximum weakness not being concentrated along a fixed axis. After intrusion welded a solid buttress along the eastern border of the weak zone an axis or surface of maximum weakness was established. Lawson points out that after solidification of the Sierra Nevada batholith the axial line of the Great Valley corresponded to a tectonic hinge along which the mobile coastal region has swung ever since, in a vertical sense upon the edge of the plutonic massive (38, p. 11–12).

The shape of the pluton at depth has been deciphered by Byerly: at least for the southern part of the Sierra "there is a root which does not extend out under the valley on either side but only under the high part of the range" (9). The massive therefore does not extend westward with depth, but has the shape of a gigantic vertical dike, along the western wall of which the mobile block could slide up and down with relative ease.

Such a tremendous, transgressive surface of discontinuity and probable movement might well have been the ore channel for Mother Lode gold solutions. Certainly the deposits and their possible channel correspond in space. Was the channel there when the solutions were active? For there to have

been such a channel the main mass of the batholith must have solidified by the time of metallization.

According to Johnston (30, p. 14–16) age determinations of Grass Valley batholithic intrusives by Urry, using the helium method, indicate a span of probably five or six million years between emplacement of the granodiorite pluton and that of the youngest differentiate dikes, solidification of which was followed after an unknown interval by metallization.

Larsen estimates that a batholith such as that of Baja California would crystallize to depths of 13 to 17 kilometers below its top in about 7 million years (37, Table III, p. 409). For a yardstick to measure such epochs, the entire Jurassic according to Holmes (27) lasted about twenty-five million years.

Byerly (9) shows that the "keel" of the Sierra Nevada pluton is relatively shallow, bottoming probably well above the bottom of the mantle at the time of intrusion (40 km).

According to the above lines of evidence, the Sierra Nevada batholith was solid to a depth of at least 13 km below its top by the time metallizing solutions became active along its western wall, and since the pluton is relatively shallow, it may have been entirely crystallized by that time. If so, the source of Mother Lode metals could hardly have been a hearth of differentiation within the batholith. It is more likely that the source lay deeper than the pluton and that, since the latter was solid along its western wall at the time of metallization, ore solutions rose up the wall, probably "triggered" by tectonic movements of the mobile block adjoining the batholith on the west.

Such a conception has significant corrolaries. Although the east side of the Sierra Nevada pluton was vertical like the west side, it lay within the stable buttress and would therefore be less apt to channel ore solutions, especially those originating at great depth. This would explain the notable lack of Nevadan gold-quartz deposits on the east side of the batholith.

The lack of sizeable gold-quartz deposits associated with the Baja California batholith has been mentioned. Although these deposits lie along the western border of the *outcrop* of the batholith, there is reason to believe that the west edge of the pluton at depth lies well west of the string of gold-quartz deposits on the peninsula.

The sea-bottom off the coast of southern and Baja California, called the continental borderland by Shepard and Emery (50, p. 9, 14), exhibits a series of basins and ranges related to continents rather than to oceans. The outer margin of the borderland is shown in Figure 1. This submarine topography resembles that of the gulf (4, Plates 1 and 11; 49, Chart 1); since the area now covered by the gulf was submerged in relatively recent times, it is logical to suppose that the western borderland was also.

Small outliers of the Baja California batholith persist to the Pacific coast. The granitic stocks on Cedros Island and in the Sierra Vizcaino, if of the same age as the outliers, indicate a still farther extension of these cupolas westward, and suggest that the general top of the batholith lies here at no great depth.

On the other hand, deep sagging troughs traversed this western region in pre-batholith times (the Franciscan(?) and Alisitos troughs). After intru-

sion of the batholith geosynclinal sagging ceased; the later seas were broad, shallow, transitory. No such change occurred after emplacement of the Sierra Nevada steep-sided batholith, for the mobile belt west of it remains as mobile as ever. For Baja California the suggestion is strong that the batholith extends well west of its outcrop, and that in this western zone it wielded the belt of crustal weakness that had localized the geosynclinal troughs.

Evidence supporting this notion is furnished by the fact that the continental borderland ends to the northwest exactly opposite the northwest end of the Baja California batholith (4, Plate 11; A. A. P. G. Tectonic Map of North America).

For the central California mobile belt, it is probable that precisely the opposite conditions obtain: the coastal belt seems to have been most mobile opposite the Sierra Nevada batholith, where it could oscillate up and down using the vertical west edge of the pluton as a track.

If the above ideas are valid, lack of Mid-Cretaceous gold-quartz deposits in Baja California comparable to the Nevadan deposits of California may be due to the fact that the Baja California deposits are unconnected with a trunk solutions channel. The batholith may have a steep western side which may have lain next to a tectonically active belt in Mid-Cretaceous time and may have furnished a channel for ore solutions; but if so, the steep side and the possible ore deposits lie buried well out in the Pacific.

Ore Deposits of the Mid-Cretaceous Orogenic Belt in North America (Fig. 4B).—Spieker (51, p. 150) suggests that the main deformation in the following mining districts coincides in time and space with the Mid-Cretaceous orogeny: Ophir, Utah; Gold Hill, Utah; Goodsprings, Nevada. It is generally agreed that the lead-zinc-silver-gold deposits of Ophir, the gold-arsenic deposits of Gold Hill and the lead-zinc-silver deposits of Goodsprings formed during the waning phases of the major orogenic movements in those districts. One might tentatively add to the list of mining districts Bingham (copper-lead-zinc-silver), Tintic (lead-zinc-silver) and possibly Ely (copper).

The above districts lie along the eastern edge of the Mesozoic Cordilleran geanticline; their deposits differ from those of the orogenic belt in Baja California along the western edge of the geanticline in a number of particulars, including regional and local structural settings and especially in metal content. Where the orogenic-metallogenetic belt leaves the site of the Alisitos trough, crosses the Mesozoic geanticline and heads northeast toward Utah it leaves behind it the gold-quartz deposits of the Pacific family for an entirely different type in which base metals and silver play the dominant role.

Such a radical change might cast doubt on the reality of the metallogenetic belt as a unit and suggest that the two segments are unrelated. There are however several possible connecting links between the segments. First, the orogenic-metallogenetic belt in western Utah and eastern Nevada coincides with a segment of one of Kerr's major tungsten-bearing zones (31, Fig. 1) and although Kerr swings this zone from southernmost Nevada around the south half of the Colorado plateau, his Plate 1 suggests that the zone might with equal logic be continued southwest along the Mid-Cretaceous orogenic belt to connect with the swarm of minor tungsten deposits near the north end of the

Baja California batholith, of which the El Topo deposits (p. 66–67) are the most important in Baja California.

Second, between Goodsprings, Nevada and the north end of the Baja California batholith is a group of "pyrometasomatic" magnetite-hematite deposits which carry pyrite and often chalcopyrite as well as quartz, calcite and barite. At the Vulcan mine the limestone containing the ore bodies is early Paleozoic (34, p. 89). At the Eagle Mountain mine (24) the altered limestone and quartzite in which the ore occurs is probably pre-Cambrian. No evidence is at hand to date the stocks which invaded these rocks and the metallization closely associated with the intrusion. However, deposits similar in mineralogy lie in a belt extending for 300 miles along the western border zone of the Baja California batholith. Since some of these magnetite-hematite deposits and the minor stocks with which they are associated lie in the Alisitos formation and since the younger Rosario formation shows no evidence either of batholithic intrusion or iron metallization, the age of these deposits may be assigned with confidence to the Mid-Cretaceous period or orogeny and intrusion.

Figure 4a suggests a major extension northwestward of the orogenetic-metallogenetic belt to include the Coast Range batholith of British Columbia and its associated ore deposits. According to Lang (35, p. 5–6) a long-continued period of orogeny and igneous activity in this region during the Mesozoic culminated, probably at the end of the Lower Cretaceous, in the intrusion of the Coast Range batholith. (Age relations of the Idaho batholith and its spatially associated ore deposits are too much in doubt at present to be discussed in this connection.)

If the Coast Range batholith and its spatially associated ore deposits are in truth related to the Mid-Cretaceous orogenic-metallogenetic belt to the south, the spectacle is presented of a belt of diastrophism producing gold-quartz deposits where it was active along the most deep-seated and persistent zone of crustal weakness in all western North America, namely, the Pacific or California trough, and giving rise to lead-zinc-silver deposits where no such major zone of weakness lay along its path.

Furthermore, if the above notions are sound, gold-quartz veins of precisely the same type as those formed at the end of the Jurassic were formed in the Mid-Cretaceous, some 30,000,000 years later (Holmes, *op. cit.*); but both the earlier and the later gold-quartz deposits were limited to the zone of crustal weakness that localized the Pacific trough.

One might speculate that gold deposits of the Pacific family originated at great depth, perhaps beneath the sial, while lead-zinc-silver deposits originated much higher in the crust.

Upper Cretaceous in Baja California.—After the Mid-Cretaceous uplift, folding, intrusion, and metallization the resulting land mass was deeply eroded. The uplift on the east was so vigorous that the spine produced has remained above water ever since; but the region west of it was base-leveled by Senonian time and submerged to receive the Rosario sandstones and shales, deposited in a shallow sea, the eastern shoreline of which probably lay not far east of the present western shoreline of the peninsula (4, p. 109).

Near the end of the Cretaceous, the belt of Rosario sedimentation re-emerged; the newly-made land probably extended considerably west of the present coast. Emergence was high enough to produce a rugged topography in the belt along the present coast, but the Rosario beds from which the relief was carved were not intensely folded.

Meanwhile, in the late Cretaceous the eastern highland was worn down to a partial peneplain, and peneplanation persisted into the Eocene. The humid

FIG. 5. Pre-Pliocene Tertiary uplifts, and Tertiary-Quaternary basin-and-range faulting. Based on Eardley (15, Fig. 261).

Eocene climate produced sizeable streams that deposited auriferous gravels, remnants of which resemble Eocene gravels of the Sierra Nevada, as Lindgren noted (40, p. 192–193, 196).

Early Tertiary.—In the Eocene the relatively mobile western belt subsided moderately again to receive a sea broader than that of the Upper Cretaceous and covering the western flanks of the present peninsula. That it was quite

shallow is shown by the fact that it contained numerous islands. The silts and sandstones of the Tepetate formation were deposited in this shallow sea (4, p. 110).

Toward the close of the Eocene a major northwest uplift, Occidentalia, developed along the site of the Mid-Cretaceous orogenic belt and that of the present gulf (15, Fig. 261, p. 437; my Fig. 5). Rising Occidentalia pulled the western mobile belt up with it, but the belt dropped again during the Upper Oligocene and Lower Miocene (14, Table 10, p. 35) and this submergence for the first time admitted the Pacific across the Peninsula to the southern portion of the present gulf.

Middle and Upper Tertiary.— In the late Miocene the Occidentalia whaleback was uplifted still more vigorously and became a locus of intense and widespread volcanism, represented in Baja California by the Comondú formation (Fig. 1). That the source of these volcanics was near the site of the present gulf was recognized by Gabb (23, p. 634) and many years later by Beal (4, p. 113–114), Wilson (57, p. 1770) and Anderson (1, p. 47–48). Beal places the locus of Comondú extrusion along the axis of the Sierra de la Gigante (Fig. 1; 4, p. 113–114), a range bordering the gulf, whereas Anderson places the volcanic centers along a narrow belt coinciding with the western margin of the gulf (1, p. 47–48). Noble shows that on Punta Concepción (Fig. 1) the Comondú volcanics contain intrusive plugs suggesting an intrusive zone striking northwest along the axis of the Punta Concepción peninsula; he believes some of these necks to have been feeders for some of the Comondú basalt flows in the area (43, p. 776).

Toward the gulf, where its source fissures and necks presumably lie, the Comondú consists of a thick series of basalt, andesite and rhyolite flows and pyroclastics. To the west, down the gentle slope of the divide, these wedge into conglomerates derived from the extrusives; the conglomerates grade to sandstones of similar origin farther west (23, p. 634; 57, p. 1770; 4, p. 75). As Gabb perceived (23, p. 634) the volcanic vents lay upon an uplift (Occidentalia) down the west slope of which the lavas poured. His description of the west limb of this uplift is worth quoting:

> Another striking feature of this region is the peculiar manner of the elevation of the mesa. It has not been lifted by an evenly distributed force; not, like most mountain chains, by folding along a given axis. The eastern side seems to have felt this force almost alone, the elevation of that portion lying to the west seeming to be due almost as much to the rigidity of the rocks as to the extension westward of the uptilting power. More properly speaking, the great force was exerted very nearly parallel with what is now the coast line of the gulf, and from there toward the Pacific the agency diminished so gradually as to produce no breaks or even foldings worthy of mention.

This graphic description suggests, not tilting of a rigid block but upwarping by a vertical force concentrated along the western margin of the present gulf, which was also the locus of the vents by which the flows and pyroclastics reached the surface. These vents probably lay along fissures striking parallel to the axis of the uplift (the Occidentalia whaleback) and near its crest (Figs. 1, 5).

Uplift of Occidentalia continued after extrusion of the Comondú volcanics. In the early Pliocene fissuring gave place to faulting in the zone bordering the present gulf, for at that time a narrow forerunner of the gulf extended along the east coast of Baja California, as far as southeastern California (1, p. 48), a phenomenon best explained by faulting. Wilson shows the earliest marine beds along the present Baja California gulf coast to be early Pliocene, but thinks the major faulting along the coast to have taken place near the close of the Pliocene (57, p. 1802).

While the existence of major faults along the gulf coast is postulated mainly on indirect evidence, it can hardly be doubted. Faults known in the United States have been traced southward into the gulf and into Baja California (4, p. 93–94); Wilson has mapped a series of normal faults of considerable throw striking parallel to the coast (57, p. 1770–1771). Shepard, on the basis of submarine soundings, concludes that probable fault scarps lie along the west edge of the gulf, in contrast to the Sonora side, where little evidence of faulting exists. He finds the floor of the gulf to exhibit a pattern of fault troughs within fault troughs (49, p. 28).

Weeks (56, p. 2095) calls the Gulf of California-Imperial Valley unit a half-graben trough, formed by sag adjacent to a master fault, the sag taking place mainly by downward movement along the fault surface, with minor downwarping on the other side of the trough.

Weeks (*op. cit.*) believes the dropping of graben and half-graben blocks to have been caused by removal of material from below. Escher (19) has re-examined H. Cloos's thesis (10) that graben typically occur on the crests of uplifts formed by vertical force (tumors or *Beulen,* 11, p. 196–200) and that they result from lateral stretching of the domed or arched plate. With a dome, graben may be radial or concentric; with an elongated uplift such as Occidentalia the graben produced is longitudinal and lies along the crest of the uplift. According to Cloos's mechanics, both the graben and its frame rise with respect to sea-level, but the graben or keystone block lags behind. No removal of material below is required to effect the dropping of a Cloos-type graben.

Certainly Gabb's description of the west slope of Occidentalia (p. 25) suggests upwarping culminating along the west shore of the gulf; the zone of faulting with downthrow on the east along that shore completes a picture in accordance with the mechanics of Cloos. However, in this case an immense volume of material, that of the Comondú volcanics, was transferred to the surface from below, presumably rising along fissures that represent the initial stage of a graben fault zone. Since the trap-door action that initiated the half-graben started soon after extrusion of the Comondú volcanics, it seems certain that the half-graben block swung downward along the zone of faulting to fill the void produced by transfer of Comondú lava from depth to the surface.

It seems unlikely that the master zone of fissures and faults along the present gulf coast would have developed within a granitic massive, and more likely that they were localized along the east edge of the Baja California batholith, which is probably nearly vertical like both edges of the Sierra Nevada batholith.

Evolution of Gulf of California Compared with That of Great Basin (**Fig. 5**).—The history of the Great Basin in the following comparison is taken from Eardley (15, p. 481–485).

In the Oligocene the Sierra Nevada block was upwarped, with the axis of maximum uplift probably east of the present Sierras. In Baja California the crystalline block was upwarped in a similar manner toward the close of the Eocene. In the Sierra Nevada region the Lower Miocene marked a quiet interlude, paralleled in Baja California by subsidence on the west.

In the Upper Miocene vigorous renewed upwarping raised the Sierra Nevada several thousand feet, and the uplift was accompanied by extensive volcanism, the vents for the andesite lying probably along fissures concentrated along the west side of the crest. In Baja California vigorous uplift took place also, reaching a maximum along an axis near the west side of the present gulf. The andesitic Comondú volcanics were extruded from fissures concentrated in a zone along the west side of the crest.

Miocene volcanism in the Sierran region was closely followed by strong faulting, with downthrow on the east, along parts of the eastern edge of the granitic massive. Block faulting occurred in what is now the Great Basin. In the Baja California region extrusion of the Comondú volcanics was followed closely by major faulting, with downthrow on the east, along the eastern border of the present peninsula, which as suggested above may correspond to the eastern edge of the plutonic massive. Structure of the floor of the gulf clearly suggests block faulting.

Quiet reigned in the Sierran region during the Pliocene, but at the start of the Pleistocene the major unwarping of the plutonic block, maximal on the east, took place concurrently with gigantic normal faulting along the eastern edge of the block. Block faulting continued within the Great Basin. In Baja California and the adjacent gulf, by now fully formed, vertical movements continued during the Pleistocene and are probably still going on. Parts of the gulf continued to sink, mainly by block-faulting. The adjoining peninsula, although at first it oscillated up and down, suffered the great net uplift visible today.

The Gulf of California developed by formation of a half-graben along the crest of a long, narrow uplift, after lava extruding along the crest of the uplift had created a void below, into which the half-graben sank like a trap door. At the same time or later the hinged plate broke and suffered block-faulting. As shown in Figure 5, the Great Basin has a far different shape from that of collapsed Occidentalia, being several times as wide and nearly equant in shape. Its development therefore must have been much less simple than that of the Gulf of California; nevertheless the tectonic history of the gulf might offer a clew to that of the Great Basin. The possibility was suspected by S. F. Emmons and G. P. Merrill in 1894 (18, p. 512):

> . . . the general deduction that the depressed area of the Gulf of California and its continuation in the desert valleys of the north bears the same relation to the Peninsular Sierra that the Great Basin does to the Sierra Nevada appears to be borne out by what is known of the general structure of the former; and if, like the Great Basin, this at present depressed area was once relatively higher than

that which now constitutes the mountain range, it would have formed a barrier in the ancient ocean which would account for the faunal differences which appear to prevail between the Cretaceous life as now known on the Pacific coast, and in Mexico and Texas.

Noble also (43, p. 773) suggests the possibility that the Baja California-Gulf region, characterized by long-continued faulting, may be an extension of the basin and range topographic province in the United States.

Pliocene Metallization.—From the standpoint of mining the Pliocene was by far the most important epoch of metallization in Baja California. The Boleo copper deposit and the Lucifer manganese deposit at Santa Rosalía date from this epoch, the Boleo having been one of the great copper deposits of the world, and the Lucifer one of the largest high-grade manganese deposits in North America.

In the Santa Rosalía-Punta Concepción coastal belt (Fig. 1) Lower Pliocene faulting along the present west edge of the gulf broke off and in part submerged slivers of the peninsula. Marine and terrestrial Pliocene and Pleistocene sandstones, tuffs, clays, etc., were deposited on the subaerial erosion surfaces of these depressed fault blocks. Hypogene manganese deposits and the Boleo copper deposit, probably hypogene, formed within this coastal strip, the manganese deposits partly in Comondú volcanics underlying the Pliocene beds, partly in Pliocene tuff beds, the Boleo copper deposits in Pliocene tuff beds. The north-northwest alignment of all these deposits (Fig. 1) suggests that manganese- and copper-bearing solutions rose along fissures associated with the coastal faulting but antedating the climax of faulting and the final submergence of the gulf.

The axis of this ore zone corresponds to the locus postulated for the source fissures of the Comondú volcanics by Beal, Anderson, and Noble mentioned above. The ore deposits are younger than the Comondú volcanics; if the ore solutions and the lava both rose along fissures, repeated fissuring along the same zone is indicated, although not reopening of the lava fissures, since these presumably were sealed by lava. Repeated fissuring along a fixed zone suggests preexisting structural control; it has been suggested that the steep east side of the batholith furnished that control.

It seems possible therefore that the copper and manganese solutions of eastern Baja California, impelled by tectonic "trigger-movements," ascended the steep east side of the cold, dead Baja California batholith, as the Mother Lode gold solutions possibly ascended the steep west side of the solidified Sierra Nevada batholith, impelled by similar "trigger-movements."

TUNGSTEN DEPOSITS (22).

Tungsten deposits in the northern portion of the Sierra de Juárez (El Topo district) occur in a southward extension of the southern California Peninsular Range scheelite belt (Fig. 1).

The Sierra de Juárez district lies in the heart of the batholith, which here is mainly quartz diorite with older basic facies and abundant pegmatite dikes that strike north-northwest, parallel to the axis of the batholith, or north-

northeast, normal to the axis. Metasediments, including schist with lesser hornfels, quartzite and marble, occur as bands in the batholith trending northwest, parallel with the axes of the sharp folds in the metamorphic rocks, and as irregular roof pendants.

The occasional beds of marble grade to tactite near contacts with quartz diorite; lenses of scheelite ore occur, in some places on the marble side of the tactite, in others on the quartz diorite side, or wholly within the tactite.

Beside the contact silicates of the tactite, the ore contains quartz, calcite, pyrrhotite, pyrite, and, more sparsely, chalcopyrite and arsenopyrite. Minor magnetite and hematite are always present, with commonly a trace of gold.

Mining and milling on a small scale were conducted in the district during World War I, and resumed in 1937, continuing until exhaustion of the deposits in 1943. Production has been about 64,000 units of WO3, mainly from El Fenómeno mine, in which the 100,000-ton ore body averaged 0.7% WO3. Chances for new discoveries of scheelite ore in the district look meager.

IRON DEPOSITS.

Magnetite-hematite deposits occur in the belt of Alisitos and older(?) sediments and volcanics and their metamorphic equivalents adjoining the batholith on the west, and within the batholith near its western edge (Fig. 1). The magnetite-hematite ores all contain more or less pyrite and chalcopyrite, and the iron belt is coextensive with one of unimportant copper deposits, most of which exhibit hypogene iron oxides, so that the iron and copper deposits are genetically related and form a metallogenetic province.

As shown in Figure 1, some of the iron deposits within the belt of sediments, volcanics and metamorphics are associated with individual stocks, outliers of the main batholith and probably cupolas. Wittich (59), as quoted by Freudenberg (21, p. 196–197), describes an iron deposit south of Ensenada occurring in amphibolite schists above diorite.

The iron deposits are individually not large and they are widely scattered. Wittich (*op. cit.*) estimates 5,000,000 tons of siliceous red and brown oxide ore at Cerro Colorado (Fig. 1). So far as known, none of these deposits has been mined.

COPPER DEPOSITS OF THE IRON-COPPER BELT.

Copper is widely distributed throughout the belt, but few deposits merit notice. Some are stockworks or irregular fracture zones in diorite, others lie along tactite zones localized by contacts, either between intrusive and bedded rocks or between two bodies of intrusive rock. The writer examined one of the latter type, where a contact between diorite and quartz porphyry carries a strong tactite zone with abundant but scattered magnetite and sporadic showings of copper carbonate.

Other deposits take the form of siliceous "blowouts" carrying stringers of copper carbonates, silicates and rarely chalcocite.

A few copper deposits are vein-like, lying along well-defined fractures or faults. One, the Delfino (Fig. 1) visited by Gabb in 1867 (23, p. 636), had

been mined by open-cut and consisted of a six-foot vein between good walls. The vein carried rich carbonates of copper. Another, near San Fernando and examined by the writer, shows a flat-dipping sheeted zone about 4 feet wide beneath a strong wall. The country rock, diabase, probably is a member of the Alisitos formation, which is exposed nearby, but is possibly a basic facies of the batholith, the main body of which lies not far to the east. The sheeted zone carries small masses and stringers of chalcopyrite shot through sheared, brecciated and hydrothermally altered diabase. Quartz or other gangue minerals are sparse or absent. The deposit was worked early in the present century and attempts made to smelt the ore locally, apparently without success.

MANGANESE DEPOSITS OF THE BATHOLITHIC AREA.

South of Sierra de San Pedro Mártir and near the center of the peninsula are several hypogene manganese deposits, examined by the writer. The Santa Teresa deposit (Fig. 1) lies within the batholithic complex along a steep contact between granite and a roof pendant of metavolcanics. Near the contact both granite and metavolcanics are schistose, the schistosity roughly paralleling the contact, which is straight in plan, striking roughly east-west. The manganese deposit is tabular, dipping about 70° S. Toward its east end it lies along the contact, but toward the west it enters the roof pendant, cutting the schistosity at an acute angle.

This vein-like ore body is 1,000 feet long on the surface and averages 5 feet wide. The ore is dark, hard, massive and largely fine-laminated. Part of it is strongly magnetic, but it cannot be concentrated by magnetic separation. X-ray diffraction studies suggest that although some of the manganese occurs as pyrolusite, and although magnetite is present also, much of the manganese is present in the form of jacobsite, $MnFe_2O_4$, some occurrences of which have recently been found to be magnetic.

GOLD DEPOSITS.

Real del Castillo (Fig. 1).—According to Lindgren (40, p. 187–189) this gold-quartz district lies near the western edge of a roof pendant of chloritic schists and slates near the western border of the batholith. The metamorphic rocks, which strike north-northwest and dip steeply east, are cut by many granitic and porphyry dikes. The whole slaty series carries narrow quartz veins, some auriferous, most of which lie parallel to the slaty cleavage; but the wider, commercial veins strike east-west across the cleavage. The Real del Castillo slates reminded Lindgren of those of the California Mother Lode.

Placer and lode mining in the district date back at least as far as 1868 (40, p. 187) but production has been unimportant.

Alamo (Fig. 1).—Data on this district derive from Moehlman (42), and from private reports.

This gold-quartz district lies within the batholith near a roof pendant similar to that of Real del Castillo (Fig. 1). Quartz diorite is intruded by a swarm of basic and dacitic dikes striking northwest. Narrow gold-quartz

veins striking west-northwest and dipping steeply intersect the dike system in such a manner that the line of intersection of a vein and a dike plunges southeast at about 25°.

The quartz veins, although younger than the dikes, rarely penetrate them, the result being that where a vein-fracture intersects a series of dikes at acute angles, the plane of the vein-fracture is divided into a series of gently-pitching bands; tight, impermeable bands represent the dikes; these alternate with permeable bands between the dikes, vein quartz appearing solely in the permeable bands. In the Princesa mine the richest ore shoot, occupying one of the permeable bands, pitched southeast at 25°.

The quartz veins, which average less than a foot in width, were formed in two stages. In the first stage they attained practically their present width, the great bulk of the quartz being deposited along the vein-fracture by replacement of the diorite walls. In the second stage the early quartz was sheeted, the sheeted laminations forming channels along which the ore minerals, together with fine-grained late quartz, epidote and hornblende, were introduced.

The sparse metallic minerals include magnetite, specularite and pyrrhotite, with sphalerite, chalcopyrite and galena. Deposition was in the order named. Pyrite and marcasite also occur, believed by Moehlman to have been derived from chalcopyrite by supergene acid solutions. Gold occurs free and rather coarse, in the sulphide as well as the shallow oxide zone; its position in the time sequence is unknown. These ores formed at considerable depth, probably before erosion had cut much, if any, into the batholith.

Placers were discovered in the Alamo district in 1888, followed the next year by discovery of the rich Princesa vein ore shoot. Various companies worked the veins until 1907. In the 30's an attempt to review the district failed. Total production is somewhere between $2,000,000 and $4,000,000 (42, p. 753).

Calmalli.—Data are from private reports. The district lies in an area of schist and slate, either a roof pendant near the west edge of the batholith, or part of the belt of metamorphics bordering the batholith. The strike of the slaty cleavage is northwest, swinging in places nearly to east-west; the dip is steep. The principal vein, the Otilia, strikes east-west and dips 70°, apparently conforming to the attitude of the slates in its locality. The vein, up to 7 feet wide but pinching in places, shows ribbon structure with layers of sheared slate alternating with layers of quartz. The Otilia ore shoot pitched flatly westward and averaged about 0.6 oz gold per ton.

Gold placers were discovered at Calmalli in 1883; the chief period of lode mining was between 1891 and 1904. Combined placer and lode production may have reached $3,000,000 (5, p. 328).

GOLD-COPPER DEPOSITS OF CEDROS ISLAND.

Hutchins, in a paper on the unimportant chromite deposits of Cedros Island (28), mentions abandoned gold-copper mines near the north tip of the island; although he did not visit the mines, his mention of them seems to confirm private data concerning them.

Hutchins' map, reproduced in Figure 1, shows a granite mass near the north end of the island, within an area of Franciscan (?) slates, schists, cherts, limestones and quartzites. According to my information, which deals with gold-copper deposits presumably in this area, three mineralized sheeted zones striking northwest and dipping 70° NE have been more or less explored. Two of them were worked primarily for gold, but the third, the Esperanza, was explored for copper and developed for about 300 feet along the strike and for 300 feet in depth, proving a width of the sheeted zone of 40 feet. The zone carries heavy pyrite, with streaks of chalcopyrite, bornite, covellite and, in the upper levels, copper carbonates. Selective mining gave shipments running 13 to 37 percent copper, but the entire sheeted zone, which is more or less leached to water-level (300 foot level), averages from 0.5 to 2.0 percent copper.

SIERRA DE VICTORIA COMPLEX ORE DISTRICT.

The chief mining district in the Sierra de Victoria is that of El Triunfo-San Antonio, lying between two north-south granite prongs in an area of metamorphic rocks, largely schist, intimately intruded, largely as sills, by aplite and fine-grained granite that turns readily to gneiss (Fig. 1). A number of dikes, some of which carry small gold ore bodies, and which appear to lie between quartz porphyry and granite porphyry in makeup, occur in the area. Unlike the major ore deposits of the district, the small ore bodies in these dikes carry practically no silver and may belong to a period of metallization connected in time with the batholithic intrusion and probably much earlier, therefore, than the major, dominantly silver metallization (see below).

Dikes and irregular stocks of andesite and rhyolite or dacite indicate a period of intrusion probably distinctly later than that of the batholith.

Structure.—The dominant structural feature in the El Triunfo district is the Triunfo fault, striking east of north and dipping flatly east and seeming partly at least to parallel the flattish bedding in the metamorphic rocks, within which the fault lies. The fault consists of several parallel strands, one of which in a given locality always carries thick bullhide gouge. The gouge, the flat dip of the fault, the direction of drag in the laminated schist, and the preference of the fault planes to pick the lower surface of a competent aplite sill for a hanging wall and soft schist for a footwall all suggest a thrust.

Ore Bodies.—The Triunfo fault system is likewise the major vein system of the district, comprising three parallel veins in most localities, the Hanging wall, Middle, and Footwall veins.

At the time of the writer's visit to the district the extensive underground workings were largely inaccessible. Most of the Triunfo lode outcrop has been destroyed by surface mining. The following description, therefore, rests mainly on old unpublished reports and on a study of mine dumps.

The lode has been developed by mine workings for a strike length of 6 kilometers (3.75 miles), of which 2,300 meters or 38 percent has been more or less productive. Although metallurgical and other difficulties plus a tropical flood forced suspension of deep mining in 1895, it seems likely that the bottoms of most of the silver-gold ore shoots were reached; if so, the major

shoots all bottomed, epithermal fashion, at about the same elevation above sea-level, at an average vertical distance below the outcrop of 180 meters (584 feet), corresponding to a distance down the dip of about 360 meters (1,170 feet).

The ore shoots, in reality groups of closely spaced lenses, exhibit at least one structural control. Where both walls of the Triunfo thrust zone are schist, little or no ore was found. In such places thrusting either concentrated on one lubricated horizon in the schist or dispersed itself along a number of schist planes. In either case only weak, sporadic mineralization resulted.

Apparently all or nearly all productive shoots were found where the hanging wall of a thrust plane is aplite or gneiss, and the footwall is schist. Most of the ore shoots seem to have consisted of closely-spaced, short quartz-sulphide stringers between schist laminae that had been dragged against the hard aplite or gneiss hanging wall and pulled apart, the wedge-shaped interstices being filled by the quartz-sulphide stringers which feathered out a few feet below the hanging wall but nevertheless formed an ore lens of tabular shape parallel to the hanging wall.

The shoots averaged 2 to 3 feet in thickness.

Mineralogy.—The chief gangue mineral is quartz; white, translucent quartz is barren; dark, chalcedonic, often drusy quartz is associated with ore sulphides and may be banded with them. Sulphides made up as much as 40 percent of the ore mined, and consisted of pyrite, arsenopyrite (these two mainly intergrown with the chalcedonic quartz), dark sphalerite, galena, tetrahedrite, boulangerite, and stibnite. Smaltite also occurred.

Lateral zoning is said to be evident along the Triunfo vein system, the central stretch being characterized by pyrite, arsenopyrite and tetrahedrite, with sphalerite followed by galena coming in to the north and south. Zinc is said to have increased with depth and precious metals to have decreased radically toward the bottom of the workings.

The ore mined averaged about 8 gm gold per metric ton (0.23 oz per short ton) and 850 gm silver (25 oz.), with 4 percent lead and variable amounts of arsenic, zinc, antimony etc. This rebellious ore had to be calcined, chloridized and lixiviated or cyanided.

Production.—The El Triunfo district was discovered about 1750 (3, p. 45), but the bulk of the production came between 1878 and 1889, when according to old records metals to the value of $5,877,000 were produced. Total production is probably less than $10,000,000.

Origin of the Deposits.—The drusy, chalcedonic quartz, much of the remaining mineral assemblage and the bottoming of the precious metals at a uniform horizon, all suggest epithermal conditions of deposition. If the deposits are epithermal erosion must have cut deeply into the batholithic complex by the time of metallization and there could have been no genetic connection between the batholith and the silver-gold-arsenic deposits. Wright (61) points out that the El Triunfo district lies upon a Tertiary axis of uplift trending northwest and showing no relation to the Mid-Cretaceous structure, and that the major metallization at El Triunfo may be of Tertiary age.

MANGANESE AND COPPER DEPOSITS OF THE GULF COASTAL STRIP.

Manganese Deposits of Punta Concepción.—The gulf coastal manganese belt starts on the southeast near Loreto and continues northwest along the east shore of the Punta Concepción peninsula (Fig. 1). Noble (43) describes deposits near the tip of the peninsula. Comondú agglomerates, tuffs and basalt flows are overlain unconformably by conglomerates, fanglomerates and tuffs of the Lower Pliocene Boleo formation (Table 2). Near the mines these beds are deformed into a broad uplift, partly by warping but mainly by north-northwest faults, which antedate the metallization but continued active after that period.

Manganese occurs as countless tiny veinlets of pyrolusite and other minerals in the Comondú basalt. Although most faults in the mineralized area are barren, manganese veinlets are most closely-spaced and form the best ore in and along north-northwest fault zones, the faults of which dip west with normal displacement. The fracture pattern of the veinlets themselves, although complex, favors a north-northwest strike.

TABLE 2.

STRATIGRAPHIC SECTION, SANTA ROSALÍA AREA.

Unconformity: x x x x x

Epoch	Formation, description	Thickness
Pleistocene	Santa Rosalía. Sandstone, conglomerate	0–100′
Pliocene, Upper	Infierno. Sandstone	16–33′
Pliocene, Middle	Gloria. Sandstone, clay	160–500′
Pliocene, Lower	Boleo. Tuffs, sediments. *Copper, manganese*	300–800′
Miocene	Comondú. Volcanics, extrusive, intrusive. *Manganese*	500′ plus

Some patches of mineralization in the area exhibit copper carbonates rather than manganese minerals.

A small tonnage of manganese ore was mined and shipped from Punta Concepción in both world wars.

Boleo Copper Deposit.—The bedded copper ore bodies of Boleo occurred at five horizons in the Boleo formation; at each horizon the ore lay in clayey altered tuff, above a bed of conglomerate. The clay merges upward to unaltered tuff.

Ore persisted in general throughout the clay bed in which it lay, no structural control being apparent; but within the bed the ore was not distributed uniformly, occurring as shoots or concentrations separated by lower-grade areas (53, p. 127).

Mineralization in the ore beds is confined to the cryptocrystalline matrix of the altered tuff, fragments being barren. The matrix consists of chalcedony, chlorite, kaolinite, psilomelane or pyrolusite and zeolites. Chalcocite, the main

ore mineral, occurred in the matrix as extremely fine grains or needles (53, p. 134–135). The better ore carried about 5 percent copper.

Production.—The deposits, discovered about 1868 (44), were acquired in 1885 by the Compagnie du Boleo, organized in Paris. Between 1890 and 1948 over 550,000 metric tons of copper were produced, the gross value of which exceeded $150,000,000. According to Billingsley and Locke (6, Fig. 1) the following North American copper districts belong with Boleo according to their scheme of classification (districts showing values for past production, plus reserves, of between $50,000,000 and $250,000,000): Brittania and Rossland, British Columbia; Superior and Ray, Arizona; Nacozari, Sonora. Boleo was one of the major copper deposits of the world. It is now mined out.

Origin of the Deposits.—Theories of origin advanced by various geologists are discussed by Touwaide (53, p. 138–140). Touwaide favors a "red bed" origin, believing the copper to have been leached by descending waters from pyroxenes in tuff beds overlying the ore beds and to have been deposited as colloidal gel in the clay ore beds, which the solutions penetrated by diffusion.

Touwaide dismisses a syngenetic origin categorically and opposes a hydrothermal origin by pointing to the absence of known "feeder" fissures crossing the beds, and to the fact that the ore beds carry ore, to a greater or lesser extent throughout, and that visible structural control of ore bodies is lacking (53, p. 140–141).

The manganese deposits of the same age as the Boleo copper deposits, and along the same ore axis, may throw light on the origin of the Boleo deposit, especially since manganese occurred throughout the Boleo copper deposits. Noble (43, p. 785) postulates a hydrothermal origin for the Punta Concepción manganese deposits, as do Wilson and Veytia (58, p. 217) for the Lucifer manganese deposit adjoining Boleo on the northwest, and they conclude, since copper is widely distributed in minor amount in the Lucifer deposit, that the manganese and copper deposits had a common origin.

Wilson and Veytia point out that Park suggests, for certain Cuban manganese deposits in tuff and limestone, deposition of the manganese by warm hypogene solutions rising through the floor of a shallow sea and dropping their load in part as a manganiferous primary sediment syngenetically with the tuff and limestone being laid down there, and in part as manganese replacements in the tuff and limestone beds after sedimentation had ceased.

Such an origin for the Boleo deposits might explain a puzzling feature, the occurrence of each ore layer in an altered tuff bed directly above a bed of conglomerate. Wilson (57, p. 1779) in discussing the origin of the Boleo formation points out that its frequent tuff horizons represent recurring periods of explosive volcanism wherein ash was deposited not only over areas of lagunal deposition but also over highland areas of the landmass on the west that were being actively eroded. Before one of these volcanic periods the source material for the bedded rocks of the Boleo formation consisted exclusively of Comondú volcanics from the highland, but for a time after each eruption the only source material was ash until erosion had exposed once more the Comondú bedrock.

Confirming this notion, the top of each conglomerate bed is sharply defined beneath the clayey layer of tuff above it.

If each explosive epoch was "triggered" by movements that reactivated the northwest axis of volcanic vents, it is easy to suppose that solfataric fissures were likewise reactivated to permit ascent of copper- and manganese-bearing solutions, which deposited their metals in the shallow sea that received the tuff falling directly into it. If solfataric action ceased with explosive volcanism, the tuff laid down on the highland and brought down to the sea by streams would be barren, as it is.

Lucifer Manganese Deposit (Fig. 1).—According to Wilson and Veytia (58) the Lucifer manganese ore body lay in a tuff bed corresponding to the lowermost Boleo copper horizon; but at Lucifer the ore lay toward the top of the tuff bed, which was interbedded with conglomerate layers, and was not therefore deposited contemporaneously with the tuff from the explosive outburst. The Lucifer manganese ore in that case must owe its origin to hydrothermal solutions entering the area after explosive volcanism had ceased for the time. If so, the ore body should show evidence of epigenetic origin. The following such evidence is advanced by Wilson and Veytia (58, p. 217–219).

1. The Comondú volcanics underlying the Boleo formation carry veinlets of manganese oxide, iron oxide, copper minerals and jasper. These veinlets occur along faults.

2. The manganese oxide often transgresses from the tuff ore horizon into overlying or underlying conglomerate.

3. The manganese deposits are highly localized, and the chief deposit is structurally controlled, lying on a structural terrace trending west-northwest and being overlain by a flat fault, probably premineral.

Production.—Between 1942 and 1948 the Lucifer deposit yielded 160,000 long tons of ore averaging about 47 percent manganese; the total size of the ore body has been proven to be about 300,000 tons, most of which has probably now been extracted.

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July 17, 1953.

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THE ILMENITE DEPOSIT OF ABU GHALQA, EGYPT.

M. S. AMIN.

ABSTRACT.

The deposit is a late magmatic ilmenite ore formed by the accumulation of a late ilmenite-rich residual fluid on the top of a titaniferous gabbro mass.

INTRODUCTION.

In 1947, the writer examined the ilmenite deposit and associated rocks of Wadi Abu Ghalqa, in the Eastern Desert of Egypt. The results of this study and a geological sketch map of the deposit and the associated rocks are given in this paper. It is concluded that the ilmenite deposit is a late magmatic ore found in association with a titaniferous gabbro rock of related origin. This study was carried out with the help of Hamata Mining Co., which had kindly provided the author with field facilities.

The deposit occurs in Wadi Abu Ghalqa, which is a tributary of Wadi Abu Ghusûn, in Lat. 24° 21′ 20″ N and Long. 35° 3′ 30″ E. It is accessible from the Red Sea shore along a road passing by Wadi Ranga which runs for 18 kms from Bir el Ranga (Fig. 1).

The deposit was first described by Hume (5, p. 57) as a titaniferous hematite ore found in association with the gabbro west of Bir el Ranga. The locality was described on his map as the "Hematite Hill." It was later described by Attia (1, p. 2)[1] who gave a general description of the rocks in the area, and several chemical analyses of the ore. Both Hume and Attia have considered the ore to be a segregation from gabbroic magma, which produced the gabbro rock associated with the ore.

GENERAL GEOLOGY.

The ilmenite deposit occurs within a small body of titaniferous gabbro that lies on the eastern side of the huge granite area between Hamata and Sikait. In the area of the deposit, the gabbro body is bordered on the western side by the granitic mass of Abu Ghalqa hills, and on the eastern side by the metamorphosed rocks of Gebel El Sarobi. These two are separated by Wadi Abu Ghalqa.

The granitic rocks of this area were generally described by Barthoux (2, p. 184) and by Hume (5, p. 45) as biotite granite that becomes very quartzose at Wadi Abu Ghalqa. These rocks in general are yellowish in color, which distinguishes them from the dark green gabbro and the metamorphosed rocks.

The metamorphosed rocks on the eastern side of the Wadi possess a rather uniform green color. They extend towards the Red Sea shore forming Gebel El Sarobi. These rocks are commonly cut by numerous volcanic dikes.

Field Relations.—The relations of the ilmenite and its associated rocks are shown in Figure 1.

[1] Numbers in parentheses refer to References at end of paper.

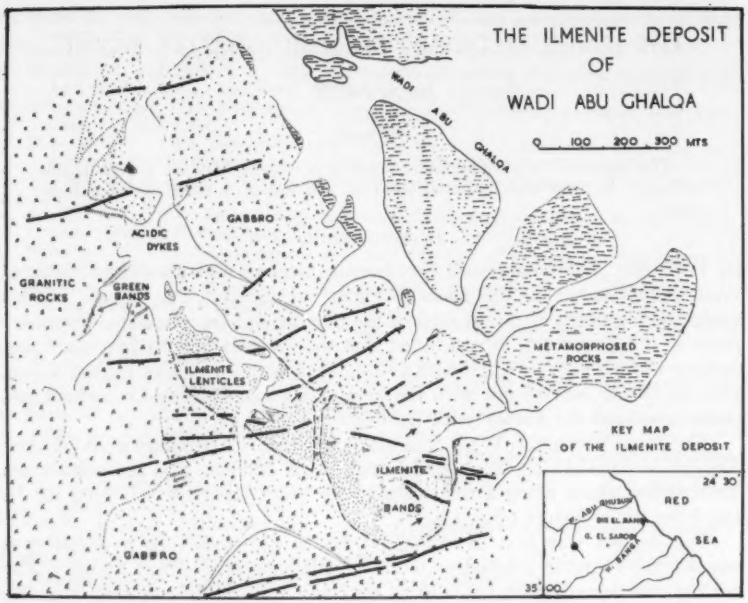

FIG. 1.

The titaniferous gabbro that encloses the ilmenite deposit forms an elongated body striking NW–SE. Its contact against the metamorphosed rocks runs generally along Wadi Abu Ghalqa (Fig. 2). It is a rather straight line contact that dips eastward. Towards the west, the gabbro merges into the biotite granite of Abu Ghalqa through a mass of granitic and dioritic rocks of mixed composition. The contact of the gabbro and the granitic rock is rather gradational within a zone of few meters. It is an irregular contact zone (Fig. 1) with saw-toothed outline.

The ilmenite deposit is confined to the titaniferous gabbro. The deposit

FIG. 2. A panorama of the gabbro mass (GB) enclosing the ilmenite deposit (I). The granitic rocks (GT) appear in the background.

forms an inclined sheet-like zone on the present top of the gabbro mass, which is made up of small ilmenite lenticles overlain by relatively larger ilmenite bands (Figs. 3A, 3B). The ilmenite bands, as well as the lenticles, strike NW–SE and dip gently to the NE, parallel to the eastern contact of the gabbro. The ore bodies also possess a layered structure in which thin layers of gabbro, massive and disseminated ore bands are intercalated repeatedly (Figs. 4A, B). The disseminated ore bands exhibit flow bands that are produced by the orien-

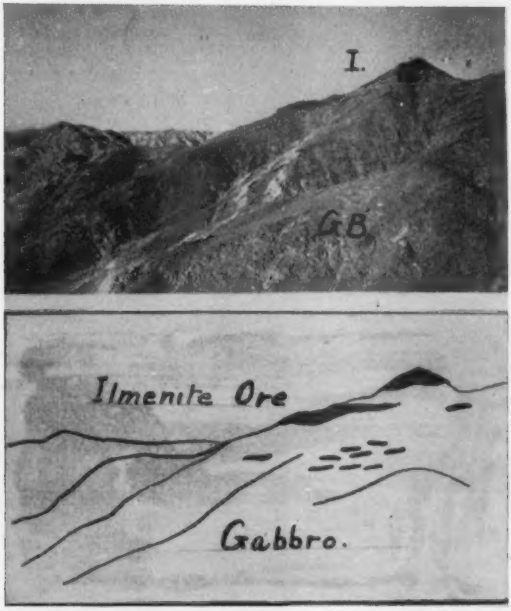

FIG. 3A. A cross-section of the ilmenite ore layers (I) on top of the gabbro (GB).
FIG. 3B. A diagrammatic cross-section view of Figure 3A.

tation of the silicate constituents in a plane parallel to the layered structure. The silicate crystals within these bands are arranged at random (Fig. 5).

The granitic rocks and the gabbro, as well as the ilmenite deposit, are commonly traversed by granite, aplite and porphyry dikes that strike westerly.

PETROGRAPHY.

The Metamorphosed Rocks.

The western flanks of Gebel El Sarobi close to Wadi Abu Ghalqa consist of massive green rock speckled in white. In thin section, it consists of saus-

suritized feldspar phenocrysts embedded in a fine green matrix of fibrous amphibole, chlorite, and little epidote. The matrix also encloses green hornblende and zeolite. This rock can be considered as altered andesite or prophylite. It is traversed by numerous granite porphyry dikes of yellow, pink and violet colors. Both the prophylite and the porphyry dikes contain cubes of pyrite. The prophylite in places is associated with some altered dioritic rocks that are extensively injected with granitic material close to the gabbro intrusion.

The Titaniferous Gabbro.

The titaniferous gabbro lies west of the metamorphosed rocks. It is, in general, a medium grained rock that is dark green in color due to its constituents of feldspar, pyroxene and/or amphibole, and ilmenite. The petrography

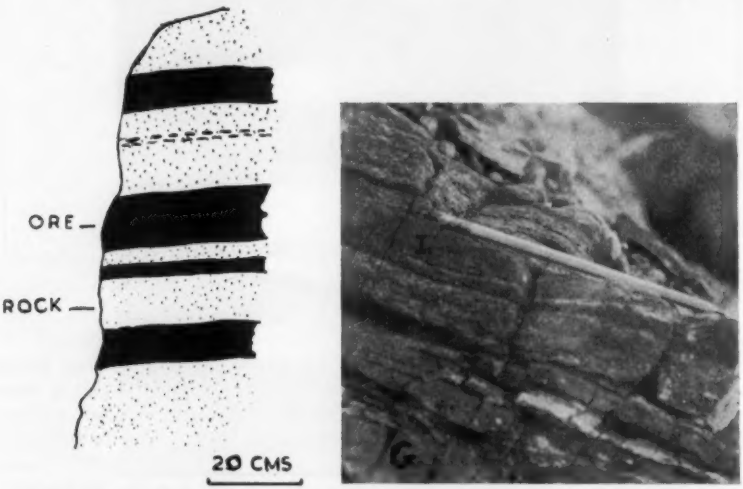

FIG. 4A. A diagrammatic section of banded ilmenite ore and gabbro.
FIG. 4B. Banded ilmenite ore (I) and gabbro (G). The massive ore merges into the disseminated ore.

of this rock indicates that it suffered extensive alteration. However, some relics of the parent rock still exist. These have a limited distribution and are recognized by their brown weathered surface.

The gabbro also encloses small lenses of fine-grained rock, as well as irregular patches and narrow dikes of pegmatitic that have the same composition as the medium grained gabbro. The gabbro in some places is traversed by bright green bands of quartz-epidote-chlorite rock, which are generally associated with quartz injected gabbro.

The fresh titaniferous gabbro of the relics is a brownish green rock with a fine to medium texture. It consists of titaniferous augite, labradorite and

ilmenite (Fig. 6). The constituents in places are foliated into narrow streaks a few millimeters in width. The titaniferous augite is pleochroic with Z = pink, Y = X = bluish green, and 2V = 65.5. It contains schiller inclusions that are possibly made of rutile needles. The pyroxene crystals may be lacy and sieved by fine plagioclase grains. The labradorite forms short prisms up to 5 mm in length, and is slightly kaolinized but densely dusted with very fine rutile needles that give the feldspar a violet tint in the hand specimen. Its composition is $Ab_{40}An_{60}$. The ilmenite is in scattered grains or streaks, and generally fills the interspaces of the feldspar or pyroxene and may enclose them poikilitically (Fig. 6).

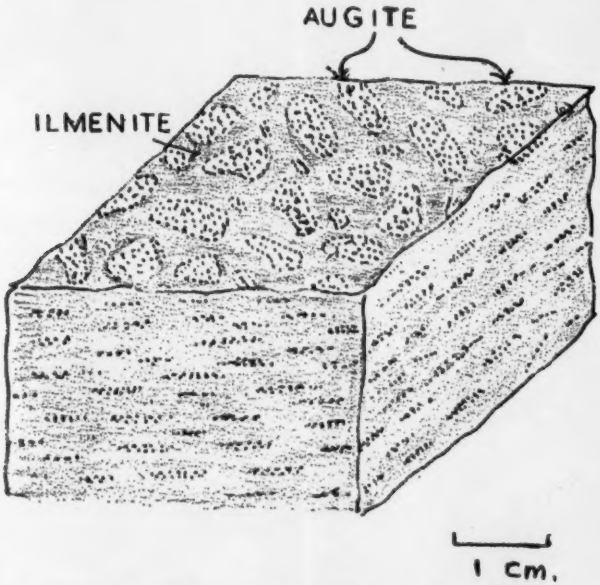

FIG. 5. Disseminated ilmenite ore, with oriented augite crystals that lie parallel to the layered structure.

The normal titaniferous gabbro mass is principally made up of amphibole, labradorite and ilmenite (Fig. 7). The amphibole is an alteration product of the augite. The labradorite is partly kaolinized, sericitized, and retains its rutile needles. The gabbro encloses some grains of ilmenite that generally fill the interspaces of the feldspar grains or enclose them poikilitically (Fig. 7).

The gabbro mass encloses some lenses of a fine-grained gabbroic rock made of hornblende, labradorite, and ilmenite. In places, porphyritic crystals of labradorite are enclosed in the fine matrix. The gradation of the fine to the medium-grained rocks can be observed even in the same hand specimen. The

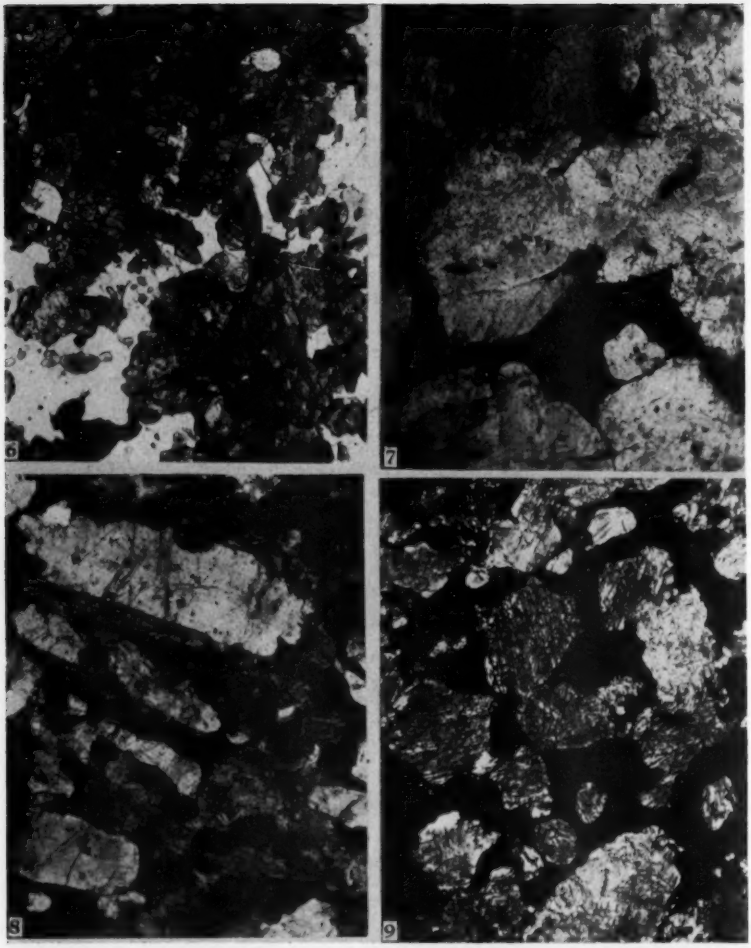

FIG. 6. Photomicrograph of a fresh gabbro made of titaniferous augite, ilmenite (black), and labradorite. The ilmenite encloses the pyroxene poikilitically. × 26.

FIG. 7. Photomicrograph of hornblende gabbro made of hornblende, labradorite and ilmenite. The ilmenite (black) fills the interspaces of the feldspar grains. × 26.

FIG. 8. Photomicrograph of a disseminated ilmenite ore, with labradorite prisms and small augite grains enclosed in ilmenite. × 26.

FIG. 9. Photomicrograph of a disseminated ilmenite ore, with titaniferous augite grains enclosed in ilmenite. × 26.

gabbro mass also encloses elongated patches of pegmatitic gabbro having the same mineralogy but generally more altered. It is also cut by a few quartz stringers. The injected gabbro contains labradorite, hornblende and ilmenite, with some clusters of biotite, chlorite and epidote. The labradorite is strongly kaolinized, and encloses magnetite octahedra. The injected gabbro is commonly associated with bright green bands of quartz-epidote-chlorite rock. These are mapped as green bands in Figure 1.

The Ilmenite Deposit.

The ilmenite is mapped either as "ilmenite layers" or "ilmenite lenticles." The former occur as regular layers several meters in length and width and are made of solid ilmenite ore. This is distinguished from the lenticular ore, which occurs as small lenses up to two meters in length, scattered in the gabbro

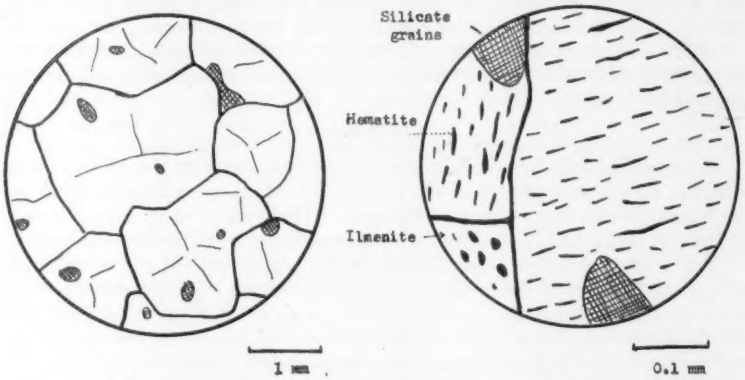

FIG. 10A. Diagrammed photomicrograph of ilmenite ore under reflected light. The ilmenite ore grains enclose a few silicate grains.

FIG. 10B. Diagrammed photomicrograph of the same ilmenite ore, with high magnification under reflected light. The ore consists of ilmenite with exsolution lamellae of hematite.

rock. The massive ore of the bands or lenses merges into the gabbro country rock through a zone of dissemination. In this deposit, it is possible to demonstrate the transition of the massive ilmenite ore to disseminated ore, and then to the titaniferous gabbro, which proves the unity of the ore and the gabbro rock. The massive ilmenite ore consists of interlocked ilmenite grains up to 5 mm in diameter. These enclose small pyroxene grains.

The disseminated ore consists of fine to medium grains of pyroxene embedded in a matrix of ilmenite (Fig. 9). The ore may enclose prisms of labradorite. The petrography of the ore indicates that the crystallization sequence is feldspar, pyroxene, and ilmenite.

Under reflected light the ilmenite discloses exsolution lamellae of hematite (Fig. 10). These form tiny bodies with an average width of .002 mm and

length of .04 mm. They are almost parallel within the same grain, but their orientation is not uniform in the different grains.

The Granitic Rocks.

Granitic rocks lie on the western side of the gabbro mass, towards the biotite-granite country of the Abu Ghalqa hills. They consist of acid plagioclase, strongly kaolinized and sericitized, and quartz, with a little chlorite, biotite and epidote. Towards the gabbro mass, these constituents increase and are associated with decomposed hornblende and the rock is dioritic. The gabbro rock near the granite contact is injected by quartz, and is strongly altered.

Some gabbroic relics occur in the granitic rocks near the contact and have been mapped as "green bands" in Figure 1. These consist of quartz, chlorite and epidote, and contain some fresh cores of the quartz-injected titaniferous gabbro. The granitic rock also encloses small relics of porphyritic gabbro.

Acidic Dikes.—The granitic rock, the gabbro, and the ilmenite deposit are traversed by several dikes of aplite, granophyre, muscovite granite and granite porphyry.

DISCUSSION.

General Geologic Relations.—The geology indicates that the gabbro mass intruded the metamorphosed country rocks, and these were later invaded by the biotite-granite masses west of the area. These rocks were later injected by the acid dikes, which cut across the regional structure of the igneous bodies.

The relation of the gabbro and the granitic rocks is perhaps one of the most interesting features in the general geology of this area. Unfortunately, lack of detailed information, and particularly of a regional geologic map, does not permit discussion of this relationship in detail. Nevertheless, the following features are considered as evidence of the invasion of the gabbro by the granitic rock.

1) the formation of mixed granitic-dioritic rock at the gabbro-granite contact.
2) the formation of quartz-injected gabbro rocks.
3) the occurrence of gabbro relics within the granitic rocks close to the contact.
4) the transitional and wavy contact zone between the gabbro and granite.

Relation of the Gabbro and Ilmenite Deposit.—In this district, the gabbro and the associated ilmenite deposit are genetically related. This is shown by the confinement of the deposit to the gabbro mass and by the transitional change of the massive ilmenite layers or lenses into gabbro rock through a zone of disseminated ore. This change, as described above, involved the concentration of ilmenite constituents on the side of the deposit and the feldspathic and ferromagnesian constituents on the gabbro side. The genetic relation of the gabbro and ilmenite deposit is also shown by their identical crystallization sequence, which is generally feldspar, pyroxene and ilmenite, in that order. These fea-

tures indicate the derivation of the ilmenite deposit from the parent gabbroic magma. The early formed minerals from this magma, namely the labradorite and pyroxene, are titaniferous, which indicates that titanium is an original constituent of the gabbroic magma, and was not introduced later. The ilmenite deposit produced from this magma consists of lenses and layers that occupy the top part of the gabbro mass and lie parallel to its elongation. It is a concordant type of deposit without indication of intrusion into or outside of the gabbro mass.

Crystallization and Concentration of the Ilmenite.—The crystallization sequence of the gabbro rock is mainly feldspar-pyroxene-ilmenite. The gabbro magma crystallization, therefore, commenced with the feldspar was then followed by the pyroxene, leaving a residual ilmenite-rich fluid. The same sequence is determined in both the disseminated and massive ilmenite ores. Applying this sequence to the interpretation of the idealized cross section of the gabbro-ilmenite mass (Fig. 3b) yields the following:

1) The formation of the ilmenite ore zone on the top part of the gabbro mass indicates that the normal crystallization of the gabbro was followed by the concentration of ilmenite-rich fluids that gathered on the top part of the mass.
2) The concentration of these late fluids was first partial and produced the lenses of ilmenite and then was completed and produced the ilmenite layers.

The layered structure of the ilmenite deposits (Fig. 4) reflects the effect of gravity on the settling of the late residual fluids. The effect is reflected also in the formation of the planar orientation of the silicate constituents of the disseminated ore (Fig. 5).

The above features permit consideration of the process of concentration of the ilmenite ore. This problem was recently dealt with by Bateman (3) who concluded that late magmatic oxide ores represent the accumulation of a residual liquid enriched in oxides, which may give rise to (1) a liquid gravity accumulation that may remain within the intrusive, or (2) may be squeezed and injected into the mother rock or into adjacent rocks, or be filter pressed elsewhere. The latter was applied to intrusive deposits while the former explained the formation of concordant stratified deposits. It is possible to explain the formation of Abu Ghalqa ilmenite deposit on the basis of liquid gravity accumulation. There, it is assumed that towards the late stages of gabbro formation, the late residual ilmenite-rich fluids were concentrated on the top part of the crystallized gabbro mass. These, under the control of gravity, settled down first as small lenses and then as bands of larger dimensions. Bateman (3, p. 424) has concluded that the deposits concentrated by this method may be accompanied by anorthosite, but such rocks are not known in the Abu Ghalqa deposit.

The formation of the ilmenite deposit by accumulation of a concentrated late ilmenite-rich residual fluid indicates that the original gabbroic magma was richer in titanium than the normal titaniferous gabbro of the country rock. This, according to an analysis of the gabbro given by Hume (6, p. 429), con-

tains 1.18% TiO_2. On the other hand, the content of TiO_2 in the ore ranges from 32.00 percent to 54.00 percent according to the analyses given by Attia (1, p. 3). The complete analyses of the gabbro and of the ore, as given by Hume and Attia, are tabulated below.

	The gabbro	The ore
SiO_2	52.53	0.85
Al_2O_3	18.32	1.16
Fe_2O_3	3.16	21.95
FEO	5.01	25.94
MgO	5.56	2.39
CaO	10.34	trace
Na_2O	3.21	—
K_2O	0.13	—
H_2O+	0.33	—
H_2O-	0.16	—
CO_2	none	—
TiO_2	1.18	46.87
ZrO_2	none	—
P_2O_5	0.22	.009
Cl	trace	—
S	0.01	—
MnO	0.19	0.38

The concentration of a late ilmenite deposit and its crystallization later than the associated silicate minerals present an important difficulty, i.e., that of keeping an oxide of known high temperature crystallization in a molten state at lower temperature. This is explained by Bateman and others as due to the effect of mineralizers and other fugitive constituents, but represents a conflict between experimental evidence and the field or petrographic evidences, which is a matter that requires further experimentation. It is not impossible to eliminate the effect of fluxes and fugitive constituents in keeping such high temperature crystallizing minerals at a lower temperature so long as the field and petrographic evidences support it.

The ilmenite ore of Abu Ghalqa is characterized by the exsolution intergrowth of ilmenite and hematite. This is different from the ilmenite-magnetite intergrowths described from any other localities, but similar to those of Allard Lake. The formation of hematite instead of magnetite is perhaps an indication of the oxidizing conditions under which the deposit was formed. Such conditions would favor the crystallization of the ferric oxide rather than ferro-ferric oxide.

SUMMARY AND CONCLUSION.

The ilmenite deposit consists of lenses and layers on the top part of a titaniferous gabbro mass. The deposit and the gabbro were produced from a titaniferous gabbro magma richer in TiO_2 than the gabbro rock. The deposit was formed by liquid gravity accumulation of a late ilmenite-rich residual fluid formed mainly after the crystallization of the feldspar and pyroxene of the magma.

ECONOMIC POSSIBILITIES.

The ore is an iron-titanium oxide. No accurate estimation of the amount of ore is known yet, but it may be of some millions of tons (1, p. 3). The

tonnage of this deposit is however limited by the extension of the gabbro mass, to which it is confined.

Further discoveries of ilmenite deposits in this area depend primarily on the occurrence of similar titaniferous gabbro masses. This may be proved by the regional mapping of the country particularly on the eastern side of the granite contact.

ACKNOWLEDGMENT.

I wish to express my thanks to N. Stradomiski of the Hamata Mining Co. for his help during my field work.

GEOLOGICAL SURVEY,
CAIRO, EGYPT,
Sept. 5, 1953.

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MANGANESE DEPOSITS OF THE MOGOLLON RIM, COCONINO COUNTY, ARIZONA.

CASWELL SILVER.

ABSTRACT.

A manganese ore province is indicated by sedimentary manganese deposits along the Mogollon Rim, Arizona. The deposits consist of hard black manganese-oxide mineral fragments in the residual soil and clay mantle, of fracture-filled veins and bedded replacement in the top of the Coconino Sandstone country rock, and of associated derived colluvial material.

SHIPMENTS of manganese oxide ore from the area along the Mogollon Rim, Coconino County, Arizona have been made from deposits genetically related to residual sedimentary deposits but differing slightly in bedrock association and form. Although the following note is descriptive only of deposits located 17 miles southwest of Heber, Arizona, and 1½ miles from the Rim, the essential facts of occurrence suggest the possibility of a sedimentary manganese province.

The Mogollon Rim is the escarpment marking a portion of the southern edge of the Colorado Plateau. It closely parallels the drainage divide between the Salt and Little Colorado Rivers, which lies in many places within 3 miles of the Rim. The area coincides with the heaviest precipitation of Arizona which ranges from 20 to 30 inches per year, much of it in the form of winter snow. Elevations range from 7,000 to 8,000 feet. The terrain is moderately rolling and in the initial stages of plateau dissection with as much as 200 to 300 feet of relief in a mile, but locally on the order of 50 feet within the area of the deposits. Close to the Rim, strong, youthful, deep canyon dissection exceeds 1,000 feet. Ground-water levels vary considerably with the seasons but in the immediate vicinity of the deposits permanent ground-water tables are either irregularly perched or deep. Heavy stands of mature western yellow pine with a thin oak and cedar undercover help retain a heavy humus mantle and residual clay subsoil.

The Permian Coconino sandstone is the country rock. The formation is predominantly a white to buff, cross-bedded sandstone that is widely distributed in northern Arizona. The typical Coconino is a uniformly fine-grained, nearly pure quartz sandstone with siliceous cement. It crops out on the rim of the Grand Canyon 100 miles to the northwest where it is about 500 feet thick, and it thickens to the south and southeast to 700 to 1,000 feet on the Rim in the vicinity of the deposits. It is considered to be a wind-laid (aeolian) sandstone.[1]

[1] Reiche, Parry, 1938, An analysis of cross-lamination in the Coconino sandstone: J. of Geol., vol. 46, p. 905–932.

Overlying the Coconino, a mile or two to the north of the deposits, is the Kaibab limestone, a light-gray weathering massive or slabby dolomitic limestone. Elsewhere the limestone is cherty, sandy, or contains thin shale beds.[2] The limestone is also of Permian age and is 200 to 400 feet thick. A transition zone of interbedded limestone and sandstone between the top of the Coconino and the base of the Kaibab is suggested in the vicinity of the de-

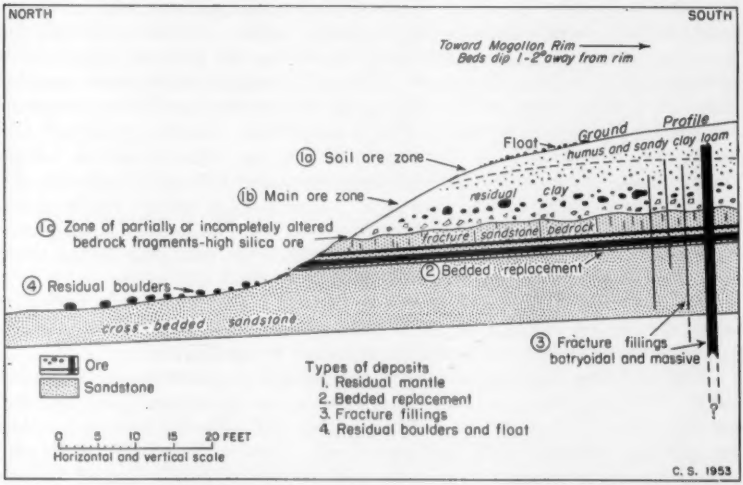

FIG. 1. Composite diagram showing forms of manganese deposits near Mogollon Rim, Arizona. Any combination or all forms may be found together. Types: 1a. Soil-ore zone; loose soil and litter containing small fragments; "knife-blade" shape and small lump. 1b. Main ore zone. Can be concentrated by washing. Nearly completely replaced bedrock fragments, balls, nodules, fragmental "knife-blade" ore; concretionary concentric bands around sandstone nuclei. 1c. Broken bedrock zone; incompletely replaced angular bedrock fragments. 2. Bedded replacement. Replacement of thin sandstone partings—"knife-blade" ore formed by replacing cross-laminae and massive ore by solid replacement of whole beds. High-silica ore where replacement is incomplete. All gradations of replacement of sandstone present. 3. Fracture fillings. Reniform, botryoidal, and massive. Resistant relic fracture fillings form ribs in residual clay zone. 4. Residual boulders and float at topographic levels below main ore zones. Boulders 1–2 feet in diameter exposed on surface.

posits, although a sharp demarcation can also be found. The manganese deposits rest on or occur within this transition zone or the upper part of the Coconino where a transition is absent. The beds dip 1° to 2° generally northward away from the Mogollon Rim.

The deposits are concentrations of manganese oxides in the residual soil

[2] Harrel, M. A., and Eckel, E. B., 1939, Ground-water resources of the Holbrook region, Arizona: U. S. Geol. Survey Water-Supply Paper 836b, p. i–iv, 19–105.

and clay mantle lying above bedrock, or replacements and fillings in the uppermost bedrock layers. A simple classification into four principal types would consist of (1) residual mantle, (2) bedded replacement, (3) fracture fillings, and (4) colluvial material as shown in Figure 1.

The residual mantle type labeled Type *1* in Figure 1 may be effectively zoned. Zone *a* is a dark brown humus and soil zone near the surface where scattered small fragments of cominuted hard manganese, generally less than one inch in greatest dimension, occur in low concentrations. All ore fragments in this zone are 100 percent manganese oxide. Zone *b* is probably the most important economic occurrence as it contains the greatest concentration of fragments both large and small. This is the body of light brown residual clay. In it occur large nodules that appear to have developed from accretionary growth as well as replaced bedrock fragments. Masses up to two feet in greatest dimension occur but mostly in size less than 10 inches. Most fragments in Zone *b* are 100 percent manganese oxide but some fragments still contain incompletely replaced sandstone. Zone *c* is the broken rubble at the base of the residual clay immediately above bedrock. In it angular sandstone fragments weathered from bedrock or residual from overlying layers show every degree of replacement of buff sandstone by black manganese oxide.

Another type labeled *2* in Figure 1 consists of replacement layers within or below the highest bedrock layers in place. Horizontal seams of solid manganese oxide up to four inches thick are present in one locality.

The sandstone shows gradational replacement from sandstone to manganese oxide. The uppermost bedrock surface displays a replacement rind, and flat ore seams are developed along bedding planes and cross-laminations forming ore partings between beds and cross-beds. Broken fragments of blade-shaped ore up to one-half inch in thinnest dimension, locally termed "knife-blade" ore, occur in the mantle and may be residual fragments of replaced cross-laminae or thin bedding-plane partings.

A third type labeled *3* consists of fillings of vertical joints, fractures, and other openings filled with manganese oxides. Such fissure veins (fillings) occur in widths up to one foot or more. Where the mantle is thick, such fissures may extend through the residual clay indicating that they may have been formed between wall rocks that have since been weathered down at least the thickness of the mantle.

The fourth type, labeled *4*, consists of colluvial material lying in topographically low areas where residual clay has been partially or completely stripped by erosion. In one locality, large boulders up to two feet in diameter apparently weathered from other types lie on the surface.

There is no evidence in the area of any carbonate or silicate mineralization that could be attributed to hydrothermal action nor any sedimentary deposits indicative of spring action. No igneous rocks are associated with the deposits. There appears to be some correlation between the thickness of residual clay in Zone 1 and the total quantity of manganese ore but thin clay zones are not richer ore areas. A ready explanation for the deposit appears to lie in the weathering of the once-overlying Kaibab limestone. At Long Valley, 65 miles to the west, the manganese oxides are reported to occur at the base

of the Kaibab. Both the manganese and the clay could be residual accumulations or concentrations of widely disseminated minor constituents of the Kaibab limestone.

This type of deposit is typical of many sedimentary ore deposits and closely resembles the residual manganese deposits of Arkansas except that here the bedrock is predominantly sandstone as contrasted with limestone in Arkansas. However, as in Arkansas, the ore most likely results from the weathering of overlapping manganiferous beds, in this instance the Permian Kaibab limestone, or beds in the still higher Triassic Moenkopi formation. The manganese and clay which may have been widely disseminated in extremely low concentrations in the overlying rocks have been concentrated by weathering in place.

The deposits appear to be localized on the ridges forming the surface drainage divide between the Salt and Little Colorado Rivers. This physiographic feature may define the area of a sedimentary manganese province.

ALBUQUERQUE, N. MEX.,
July 14, 1953.

A METHOD FOR THE PETROGRAPHIC ANALYSIS OF COMMERCIALLY DELIVERED LIGNITE.

ALFRED TRAVERSE.

ABSTRACT.

A petrographic study has been made of a column sample and of crushed commercially delivered lignite from Dakota Collieries mine, Zap, Mercer County, North Dakota. A technique has been developed for preparing thin sections of samples of the crushed lignite by embedding the particles in plaster of Paris with a plastic resin binder and then using conventional polishing techniques. Microscopic analysis was made by the usual Bureau of Mines petrographic method, slightly modified. Evidence is presented that results of such an investigation of crushed delivered lignite are closely comparable with an overall analysis of a column sample and that this method can be used for a petrographic survey of the delivered product of lignite mines.

INTRODUCTION.

In the summer of 1951 research in coal petrography and paleobotany was begun in the new lignite research laboratory of the Federal Bureau of Mines in Grand Forks, North Dakota. This is the first laboratory on this continent devoted solely to the study of lignitic coal, its composition and utilization. The problems facing the coal petrographer were unique in several respects. The research program was to be concentrated primarily on one rank of coal from one coal region, representing principally one member of one formation. This coal has been relatively little exploited or studied. Also, the research in coal petrography was to be intimately integrated with a program of research in industrial uses, especially gasification, of lignite. Hence, the problem is basically one in applied science.

At the outset it was decided to use the methods of petrographic analysis and classification developed by Thiessen and his co-workers and successors in the Bureau of Mines. The method and hence its terminology are strictly microscopic, developed for examination of thin sections of coal by transmitted light. By producing thin sections with the usual petrographic grinding and polishing techniques, lignite can be studied in presumably unaltered condition. Demineralization and other modifying treatments necessary for the microtome sectioning so commonly used for paleobotanical studies of lignite are avoided. Yet the quality of the sections is acceptable.

Teichmüller (4) [1] has pointed out that constituents of coal that are opaque in thin section can be adequately studied only by reflected light. She emphasizes that, ideally, reflected light and transmitted light should be used in conjunction for studying polished sections of coal. The author agrees with this view, but for the purposes of the present survey investigation detailed

[1] Numbers in parentheses refer to Bibliography at end of paper.

study of the opaque matter was not considered essential. All of the work reported here was done with thin sections examined in transmitted light. (On the other hand, much of the German work on the petrography of brown coal has been done exclusively with polished surfaces in reflected light.)

Using the definitions employed by Thiessen and his successors, as published by Parks and O'Donnell in 1948 (2), classification of the lignite substance into the petrographic constituents anthraxylon, translucent attritus, opaque attritus, fusain, and mineral matter is relatively simple and unequivocal, although undoubtedly refinements of the classification are possible. Nor is there any doubt that anthraxylon, for example, means something different in chemical properties for bituminous coal from what it means for lignite. The classification was accepted as a basis for work because various studies of the Bureau of Mines have shown that these constituents *do* have chemical correlatives. The definition of anthraxylon as particles of plant tissue with cellular structure, exceeding 14 microns in vertical extent in the coal bed, has been used, realizing that, far from being composed only of woody and bark tissues, many other plant parts are included—leaves, roots, fruits, seeds, and scales.

Apparently, a petrographic component such as anthraxylon will not be as meaningful for lignite as for higher rank coal. For example, Barghoorn and Spackman's work on the Brandon, Vermont, lignite, published in 1950 (1), shows that wood of two species and fruits of a third in that lignite differ widely in chemical properties. All these would be classed as "anthraxylon" in a Bureau of Mines petrographic analysis. This emphasizes that students of the structure of lignite must realize that paleobotany is enmeshed even more closely with coal petrography in the study of lignite than in the study of higher rank coals. The plant constituents are much less altered chemically than in bituminous coal, a fact that is especially significant because the plants that contributed to Tertiary lignites are represented in the *living* flora by close relatives, making possible more precise paleobotanical studies than are possible with older coals. For example, Barghoorn and Spackman (1) have also shown a relation between chemical properties of the plant parts in lignite and comparable parts in related living species. A purely petrographic analysis of a Tertiary lignite should not be regarded as more than a reconnaissance survey.

German investigators of the petrography of brown coal have developed a system of classification and terminology rather more complex than the Thiessen system. Thiessen's classification does offer the advantage of simplicity; while modifications of it for use with lignite may be necessary in the future, they should wait for further development of our knowledge of the microstructure of American lignites.

STUDY OF A COLUMN SAMPLE FROM DAKOTA COLLIERIES MINE.

With these facts in mind, an intensive study of the coal from one mine, the Dakota Collieries mine, Zap, Mercer County, North Dakota, was begun. Such a study of a coal that is used in pilot-plant research by the Grand Forks station promised to yield much information about the course our petrographic research should take in the future to be of maximum use in the industrial research at this station.

TABLE 1.

PETROGRAPHIC ANALYSIS OF A COLUMN SAMPLE OF LIGNITE FROM THE DAKOTA COLLIERIES MINE, ZAP, MERCER COUNTY, NORTH DAKOTA.

The bed of lignite from which the column was taken is 12 feet 1 inch thick, and the column was 11 feet 11¾ inches long. 188 thin sections were prepared, covering 92.2% of the bed of lignite.

	Percent
Anthraxylon	53.6
Translucent attritus	31.0
Opaque attritus	11.9
Fusain	2.1
Translucent mineral matter	1.0
Pyrite	.3

The lignite mined at the Dakota Collieries mine is from the Tongue River member of the Fort Union formation (Paleocene), as is most North Dakota lignite. The lignite bed mined is a large and important one—the Beulah-Zap bed. In July, 1951, a column of fresh lignite was collected in the mine from the 12-foot 1-inch part of the bed then being mined. The column was 11 feet 11-¾ inches long (not 10 feet, as reported by typographical error in the published abstract of a paper presented by the author to the S.E.G. Coal Com-

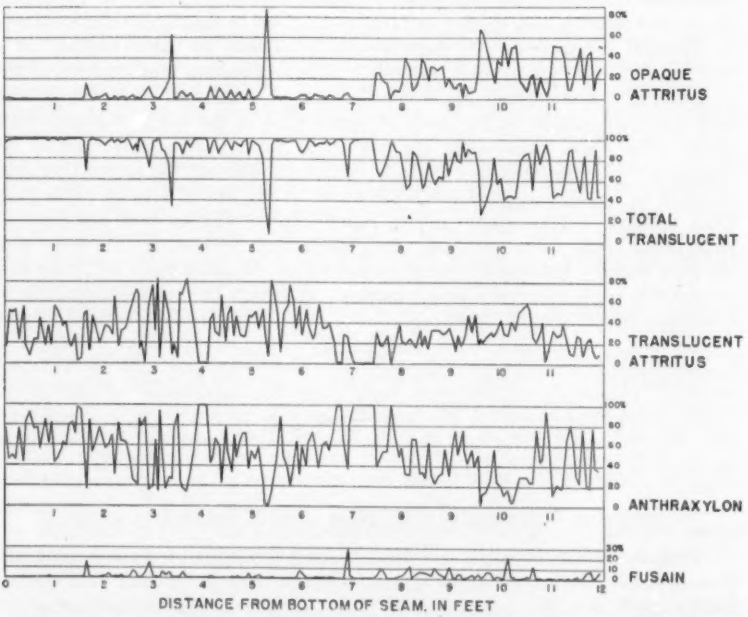

FIG. 1. Petrographic constituents of a column of lignite from Dakota Collieries mine, Zap, Mercer County, North Dakota, plotted by slide against the vertical extent of the seam. (Total translucent is anthraxylon plus translucent attritus.)

mittee meeting in Boston in November, 1952). A series of 188 thin sections from bottom to top of the column covered 93.0% of the column of lignite or 92.2% of the entire bed. The petrographic constituents of the column were determined by the Whipple disk method described by Parks and O'Donnell (2), except that all measurements were made at the same magnification, using a 15 × ocular and a 10 × objective. The results of the analysis are given in Table 1.

These figures compare quite closely with those reported by Parks and O'Donnell in 1950 (Selvig *et al.* (3)) for Beulah mine (Knife River Coal Mining Company mine, Beulah), Mercer County, a mine near the Dakota Collieries mine. Both mines work the Beulah-Zap bed. The figures for Beulah mine represent an analysis of only 32% of the lignite bed, but it is interesting that the percentages of opaque attritus—11.9 for Zap and 15.4 for Beulah—are somewhat higher than the percentages of that component reported for lignite from other sections of North Dakota. For example, Parks and O'Donnell report 3.8% for Baukol-Noonan mine, Divide County.

The percentage of the several petrographic constituents in the column is heterogeneous, even from section to adjacent section. When plotted by slide, the data show this variation clearly, as seen in Figure 1. Despite the heterogeneity, a marked concentration of opaque attritus is observable in the upper 4-1/2 feet of the column. This is correlated with differences in the gross nature of the lignite. The predominance of earthy, soft lignite with a very dark brown or almost black streak was noted in making sections from the upper part of the column. This contrasted with the predominantly light brown streak of the lignite from the part of the column that yielded sections with a relatively high percentage of translucent constituents.

STUDY OF DELIVERED LIGNITE FROM DAKOTA COLLIERIES MINE.

Investigations of column or core samples are important in determining the distribution of constituents within a coal bed, but engineers making pilot-plant studies are even more interested in the properties of commercially delivered lignite, specifically of the material used in their studies.

Hence, the next step in this problem was to develop a technique for studying delivered lignite. An approximate analysis of the delivered product can be made by making thin sections of a carefully selected sample of lumps. It is evident, however, both because fines are discarded and because small lumps are difficult to handle, that there is a likelihood of over-representation of large lumps by this method. A more truly representative sample of a given quantity of delivered coal is obtained by dividing and redividing a large sample, crushing the representative sample thus obtained to minus 1/8-inch size, for example, and reducing this further in a small sample divider. Samples for chemical analysis are so prepared in our laboratory. Hence, development of a technique for petrographic analysis of such samples was desirable, both because they are better samples and because our engineers would be especially interested in a petrographic study of the same samples for which chemical analyses are run.

The Plaster of Paris Technique for Crushed Lignite.—A technique was developed for petrographic study of samples of crushed lignite in which the particles of lignite are embedded in dental plaster of Paris and slices of the resulting block are then ground and polished to produce thin sections by the conventional methods. The method is as follows:

1. A small paper box, about 4 by 3 by 3 cm., is made by cutting and folding an ordinary filing card and sealing it on the outside with adhesive tape. This box is used as a mold.

2. About 15 grams of plaster powder [2] is placed in the paper box. Water may be used to make a thin paste of the plaster of Paris, but a water-resistant and much stronger block is obtained when a plastic resin is used as a binder. Such a resin, "Melmac Orthopedic Composition" (product of Davis & Geck, Inc., a unit of American Cyanamid Company), has been used in this laboratory with very satisfactory results. 47 ml. of warm (about 40° C.) water is mixed with 28 grams of Melmac Orthopedic Composition (a powder) and 1.8 grams of the catalyst (an ammonium chloride supplied in a separate envelope). The resulting solution is used instead of water to make a thin paste of the plaster of Paris powder.

3. A sample of about 10 grams of minus 1/8-inch size crushed lignite is then added to the paste and quickly and thoroughly combined with it, using a small spatula to mix plaster and coal until the plaster begins to thicken, which takes only about 3 minutes.

4. The mixture becomes hard in about 10 minutes, forming a block of plaster with the particles of lignite firmly embedded in it. Best results are obtained if the thin sections are prepared soon after the blocks are made because the lignite weathers slowly, even though embedded in the plaster. The paper is peeled away from the block, and thin sections can then be prepared as if the plaster block were a block of coal. (Water is used more sparingly with the block when the plaster is mixed with water alone; if the resin binder is used, water can be used as freely as desired in grinding and polishing.)

5. A surface of the block is polished, using a fine Belgian hone for the final polishing. The smooth surface of the block is fixed to a microscope slide with the customary Canada balsam and marine glue adhesive, and a Carborundum disk saw (or an ordinary band saw) is used to cut through the block about a quarter of an inch from the slide. The block is then set aside for further use, and preparation of the thin section is continued. The section is polished on a Carborundum wheel and, finally, on a Belgian hone. Polishing is continued until the particles of lignite are as thin as desired. Occasionally, particles break away from the adhesive, but such loss of particles is presumably random. As many sections as possible are made from each block.

Dental plaster of Paris with a plastic resin binder combines a number of advantages as a matrix:

1. It is worked cold, essential for success with such a high moisture coal as lignite.

2. The plaster has no apparent chemical action on the lignite, as contrasted with organic substances, many of which have an extractive effect.

[2] Dental plaster of Paris C-139, as supplied by Fisher Scientific Company, was used.

3. Dental plaster of Paris is smooth, polishes easily, and has a hardness close to that of lignite, an essential feature for satisfactory polishing. Plaster blocks prepared with Melmac Orthopedic Composition plastic resin are strong and water resistant.

Figure 2 is a photomicrograph of a portion of a slide prepared by this technique, showing the fair quality of the sections of individual particles.

FIG. 2. Photomicrograph by transmitted light of a portion of a thin section of particles of crushed delivered lignite from Dakota Collieries mine, Zap, Mercer County, North Dakota. The particle in the lower right is entirely anthraxylon, as is that in the center. The particle at the top is mostly anthraxylon, with some translucent attritus, and that in the lower left consists of anthraxylon as well as attritus of both translucent and opaque types. × 45.

Analysis of Crushed Delivered Lignite from Dakota Collieries Mine by Means of the Plaster Technique.—The basic sample used was ten 55-gallon drums of delivered stoker-size coal from the Zap mine, rescreened to ⅜ by 1½-inch size. This was obtained by intermittent sampling of a carload of Zap coal, as it was used in a pilot-plant gasification investigation ("run 17"—1951)

at this station. The delivered coal is rescreened prior to gasification and, hence, sampling. The ten drums of lignite were reduced in a large sample divider to about 10 pounds, working as quickly as possible to prevent excessive loss of moisture. This coal was then crushed in a laboratory-size Williams swing-hammer mill to minus ⅛-inch size. With a small riffle sampler, the coal was divided to produce a 1-quart sample, taken to be representative of the ten drums. This was used as a stock sample. The small riffle sampler was used to take 10-gram samples from the stock sample. Each 10-gram sample made one plaster of Paris block for preparation of thin sections as described in the preceding section. From each block about eight slides were produced. Fifty-five slides were made.

Petrographic analysis was carried out with the basic techniques described by Parks and O'Donnell (2), but a few modifications were necessary because of the nature of the material. Three transects per slide were measured instead of the conventional two. These transects were marked by dots on the slides, so that they may be repeated. All constituents were measured at a single

TABLE 2.

PETROGRAPHIC ANALYSIS OF CRUSHED DELIVERED LIGNITE FROM DAKOTA COLLIERIES MINE, ZAP, MERCER COUNTY, NORTH DAKOTA, COMPARED WITH RESULTS FOR A COLUMN SAMPLE FROM THE SAME MINE.

The data for the column are those from Table 1, recalculated to a mineral-matter-free basis.

	Column	Crushed delivered lignite
Mm. of lignite crossed in transects of slides	3395.6	551.2
Number of slides	188	55
	Percent	Percent
Anthraxylon	54.3	51.1
Translucent attritus	31.4	38.2
Opaque attritus	12.1	10.4
Fusain	2.1	.3
Total translucent matter	85.7	89.3
Total opaque matter	14.2	10.7

magnification, using a 15 × ocular and a 10 × objective. Translucent attritus was measured directly, not computed as the difference between total coal measured and all other constituents, as is customary with entire thin sections. Direct measurement is much easier and at least as accurate in studying preparations of particles because a large part of a transect across a slide is devoid of coal and therefore no simple measurement can be made of total coal traversed, as is possible for entire sections. Except for these modifications, the percentage of petrographic constituents of each particle of lignite crossed in a transect was determined with the Whipple ocular disk in precisely the same manner as for ordinary thin sections.

Caution must be exercised to prevent mistaking particles of plaster, which are opaque, for opaque coal constituents. The author used a small spotlight source of reflected light from the side of the microscope stage, in addition to the usual source of transmitted light. The plaster can thus be identified readily by its distinctive whiteness in reflected light. The reflected light is used intermittently, whenever there is any doubt about an opaque particle.

A basic assumption, which seems justified, is random orientation of the particles. The measurement is taken exactly as the transect of the slide crosses each particle. If a given particle contains only a narrow band of anthraxylon but the transect of the slide crosses the particle parallel to the horizontal plane of the original coal bed, through this band, all of the particle is counted as anthraxylon. It is assumed that the particles are oriented randomly and that hence the average measurements are valid; that is, if the sample is representative and if enough particles are crossed in transects, the different components will be crossed in the same proportion as they occur in the coal, and the percentages of the petrographic constituents so measured are valid.

The size limitations for anthraxylon (14 microns) and fusain (37 microns) employed in the Thiessen system refer to vertical extent in the coal bed. This presents no problem in the study of particles of North Dakota lignite. Both the smaller and larger bands in the lignite are invariably horizontal, and the structure of wood and bark is nearly always oriented the same way. Hence, the original horizontal plane of the coal bed is evident from the structure of all

TABLE 3.

STATISTICAL DATA FOR STUDY OF 55 SLIDES OF CRUSHED DELIVERED LIGNITE FROM DAKOTA COLLIERIES MINE, ZAP, MERCER COUNTY, NORTH DAKOTA.

Measurements are those for each of the 55 slides, considered individually.

	Minimum measurement %	Maximum measurement %	Mean ($\bar{X}$) %	Standard deviation of measurements (σ) %	Coefficient of variation $V = \frac{\sigma}{\bar{X}} 100$ %
Anthraxylon	20.6	90.5	52.5	18.0	34
Translucent attritus	7.5	66.8	36.6	14.8	40
Opaque attritus	.1	40.6	10.8	7.9	73

but the smallest particles. Some particles of translucent material less than 14 microns in diameter, though probably originally from anythraxylon bands, may be lumped with translucent attritus, and some particles of fusain less than the required size may be lumped with opaque attritus. These small particles constitute a very small fraction of the whole.

The results of the analysis are compared with the results for the column in Table 2. It is apparent that the results for the crushed delivered coal are quite close to to those for the column. The delivered coal contains less fusain, as would be expected. Fusain is extremely soft and friable and is easily lost when lignite breaks along fusain layers during preparation procedures. Similarly, the smaller amount of opaque attritus is probably accounted for by loss of some of the soft, earthy, opaque material. Reciprocally, this smaller amount of the opaque constituents means that the relative amount of total translucent matter (anthraxylon and truslucent attritus) is larger in the delivered coal.

Considering the measurements for each slide individually, Table 3 gives the pertinent statistical data for the most important constituents. Evidently, the measurement for opaque attritus is the most erratic; that is, it has the

largest coefficient of variability. Yet, the expected effect of increasing the number of slides ($= N$) to 100 would be to reduce the standard error of the mean ($= \sigma/N$) for opaque attritus from 1.2 to 0.6, an increase in precision not worth the extra labor in this sort of study. The original decision to use about fifty slides was arbitrary.

Work is in progress on similar analyses of the delivered product of other lignite mines. These can be compared with each other and with studies of column samples. More evidence on the degree of precision of this method should develop from these studies.

The most important result of this investigation is that it indicates that this technique will be useful in studying representative samples of crushed commercially delivered lignite. A survey of the delivered product of the most important lignite mines in North Dakota can be started without waiting for completion of laborious column studies, though these are necessary and desirable to establish distribution of constituents within the seam.

ACKNOWLEDGMENTS.

The author wishes to acknowledge the help of B. C. Parks and H. J. O'Donnell, of the Coal Constitution and Miscellaneous Analysis Section, Bureau of Mines Central Experiment Station, Pittsburgh, who instructed him in the procedures of coal petrography used by the Bureau of Mines.

He is also indebted to A. C. Burr, Director of the North Dakota Research Foundation, for help in the statistical analysis of the data reported here.

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July 12, 1953.

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SCIENTIFIC COMMUNICATIONS

LOW TEMPERATURE AUTHIGENIC MAGNETITE.

S. A. FRIEDMAN.

Magmatic or hydrothermal occurrences of magnetite are so common that they lead one to assume that nearly all magnetite was formed under conditions of high temperature. This communication presents some facts to indicate that some magnetite has been deposited by meteoric solutions, probably under conditions of low temperature.

Von Gumbel (5) [1] and Rosler (3) implied that magnetite deposited in rivers and streams had formed at low temperatures from meteoric waters. Leith and Mead (2) stated that magnetite cores are found in some of the hematite granules that occur in the upper part of the Cuban residual iron ores, where the magnetite is a result of precipitation during weathering.

Spiroff (4) stated that magnetite crystals occurred in vugs and as a filling in the leached iron ore in the Kinney conglomerate found on the Mesabi Range, Minnesota. These magnetite crystals were octahedrons ranging up to one inch in diameter, and were believed to have been precipitated from meteoric solutions. Spiroff grew magnetite crystals in a laboratory under conditions of low pressure and low temperature in order to test this belief.

Friedman (1) stated that magnetite grains were present in a few of the insoluble residues from the Maxville limestone (Mississippian) of southeastern Ohio. The writer believes that the magnetite is authigenic and was formed by deposition from meteoric solutions at low temperatures. This belief is held due to the fact that the localities where the magnetite occurs in southeastern Ohio are far from any area of past vulcanic activity. Furthermore the magnetite is associated with granular secondary hematite in irregular shapes, some of which suggest fossil fragments. A few of the magnetite grains are octahedrons, .01 mm in diameter, and could be secondary since they show no sign of abrasion.

Thus the writer has shown that authigenic magnetite may be more common in occurrence than is believed, and that authigenic magnetite has been formed in a Mississippian limestone from meteoric solutions under conditions of low temperature and low pressure.

INDIANA GEOLOGICAL SURVEY,
BLOOMINGTON, IND.,
Oct. 21, 1953.

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REVIEWS

Histoire Géologique de la Biosphère. La Vie et les Sédiments dans les Géographies Successives. By HENRI TERMIER and GENEVIÈVE TERMIER. Pp. 721; 35 paleogeographic maps in color; figs. 117; numerous tables and plates. Masson & Cie, Editeurs, Paris, 1952. Price, 8,600 frs. paper bound; 9,200 frs. cloth bound.

In the introduction, the authors declare: "This book, dealing with general geology, takes its place between textbooks and memoirs on pure research, but is closer to the first than to the second."

One might be surprised by such a statement for this book cannot be intended as a geological textbook in the usual meaning; in fact, there is nothing concerning eruptive rocks, metamorphic rocks, tectonic principles, metamorphism, broad orogenic hypotheses.

I should not like this remark to be taken as a criticism tending to diminish the value of a remarkable work. H. and G. Termier have focused all their attention on one of the main aspects of geology: the connections between the living world and the mineral world as they appear to those who devote themselves especially to stratigraphy, paleontology, sedimentology, paleoecology and paleogeography. They were consequently led to establish a synthesis of the geographical evolution of the Earth, from the Precambrian up to our day.

The volume is in two parts: the first one deals with the general principles of the science of geology, with special attention to the development and the evolution of life. The main object of the second part is the reconstruction of the different aspects of the Earth's surface in the course of geologic time; it is essentially of paleogeographic character. The present review will deal particularly with the first part, assigned to fundamental principles.

In the introduction, the authors discuss the barriers that have been raised between the different sciences of the Earth as a result of increased specialization. For several years, however, scientists have tended to join their efforts toward a better understanding of the various phases of the Earth's development. That is why H. and G. Termier correlate our knowledge of living organisms with our knowledge of their geologic environment.

In order to clarify the object of the book, the authors first discuss the existence of geospheres in connection with the major discontinuities revealed by the study of seismic waves. A diagram gives in a single glance the essential characters of these successive spheres. Naturally, the geospheres that especially interest the biologist are those which are most distant from the center, for they directly concern the development of life; atmosphere, hydrosphere, and biosphere proper; the last being the most complex because it includes the hydrosphere, part of the atmosphere, and part of the lithosphere.

Life is a sort of energy taking its source from the energy of the sun's rays, by means of the chlorophyll reaction. It is through this energy that living organisms can alter surrounding materials and then unite with them. The system is thus intimately bound to its surroundings; as the latter evidently includes water, a colloidal state is the characteristic of life.

These preliminary notions form the basis for a consideration of isostasy and the notion of the balancing of crustal blocks. A very suggestive table summarizes classical data on erosion, transport, sedimentation, the structure of the resulting sediments and their further development. The authors retrace the essential characters of basins and geosynclines of subsidence. The distinction made between Cordilleran and Indonesian geosynclines is perhaps not fully justified. They are right in saying: "Geosynclines are unstable structures on continental margins, forming part of them." Consequently, they contrast with continental areas or cratons in their mobility; their evolution include the following stages: pre-orogenic, cata-orogenic (with flysch formation and rising of eruptive rocks), epi-orogenic, with a late-orogenic and a post-orogenic state leading to isostatic adjustment of the relief. The geosyncline theory explains the localization of stable areas, and the widening of shields.

For the geologist, geosynclines and basins or depressions play an important role in sedimentation; H. and G. Termier have not failed to devote a few pages to the study of this subject. They touch the delicate problem of determining whether sediments or geosyncline areas are bathyal or not; they conclude that the water there had never been very deep, except occasionally when subsidence prevailed over material deposition.

The problem of transgressions and regressions naturally follows: some sort of periodicity ought to distinguish world-wide transgressions from regional transgressions. The regional transgressions are easily explained by the process of geosyncline evolution; as for the world-wide transgressions, one must admit that no one explanation gives full satisfaction to the mind. From a biological viewpoint, these great oceanic movements play an important part in faunal migration, as well as in the formation of detrital sediments, and even of other rocks such as dolomite and bone-beds.

The authors recall familiar notions about the hydrosphere to geologists: the chemical character of fresh and salt waters, the percentage of oxygen and dissolved salts, etc. Colloids are important, as are the variations of temperature and salinity in sea water that produce shifts in oceanic environments—"transgressions" and "regressions," as it were.

The authors then discuss present knowledge regarding the distribution of life organization. In marine surrounding, light is an essential element, but it does not penetrate to great depths where organisms develop peculiar adaptations, losing their sight or acquiring phosphorescent organs. These are, however, exceptions mostly interesting to zoologists.

The physical chemistry of the sea has also a great influence because of its effect on temperature distribution which in turn affects the precipitation of carbonate salts and hence the development of species. Other factors also affect living organisms: the influence of their internal chemistry on their ecology, their adaptation to varied concentrations, the influence of pH. These ideas explain how apparently unlike organisms may be grouped in the same environment; for instance, organisms able to fix limestone and others unable. Sessile organisms depend naturally on the topography of the bottom; these are classical notions.

A chapter is devoted to the study of Schizophytes (bacteria and Cyanophyceae). The very important role played by these elementary organisms is well known; they probably were the first to appear on Earth and they are very numerous and reproduce rapidly. To bacteria are now attributed iron precipitation, sulfur deposits formation, nitrogen fixing, nitrification. Their role is no less prominent in the genesis of natural hydrocarbons.

Sea bottom mud is a favorable environment for their development; hence the

authors have contributed a useful discussion of the mode of formation of this deposit, forming either directly or through "sedimentary organisms." In addition they consider the "sulphuretum" and the role of some constituents such as boron and the radioactive elements. The pH is also of great importance here. The authors then point out that a facies expresses two phenomena: the sedimentation which has always been the result of the causes presently acting and the life which has changed steadily throughout time. The principles that rule biological associations, biotopes and their evolution, the adaptation to environmental conditions of the chief organisms from primitive life to vertebrates—these constitute the object of two chapters. A comparison within some groups between living and fossil types is particularly interesting from the point of view of the biosphere and its evolution. Data on biotopes lead quite naturally to the study of sedimentary cycles and the interpretation of geological facies, taking account of several factors: bathymetrical indices, pH indices, salinity, temperature.

A concrete example, from western Australia, taken from Teichert's work, shows the direction in which stratigraphy must presently trend, taking paleontology and sedimentology as a basis for reconstruction of former sea floors.

The authors' attention is next attracted to the study of ocean coasts, for they are probably the starting point of life. The intertidal zone is characterized by the largest variety of life and the most diverse biotopes, varying from those on rocky coasts to those on moving bottoms. This study raises a host of problems concerning pre-Cenozoic rocks with pyritous fauna and graptolite shales.

If life originated in this privileged zone, it has progressively migrated into new environments: fresh waters, continents, deep seas. Pelagic life migrates easily, though much affected by marine currents, substantial variations of salinity and temperature. Moreover, the very development of living forms is bound to that of planktonic larvae. Thus, in the course of geological times, migrations have occurred through the dispersal of larvae rather more than through that of adults. Besides transport agents, the vital needs of the organism, and its struggle for existence have also conditioned migration.

The authors consider the question of sedimentation in the deep seas, the formation of "muds" where plankton is important, the Sargasso Sea, and the deep seas benthos, because of their relation to the adaptation of living forms to these special environmental conditions. If deep sea deposits occur in the sedimentary record, however, they are probably of relatively little importance.

The role of calcium carbonate in the formation of sedimentary rocks is well known. The organisms which contribute to its deposition are discussed, especially schizophytes, algae, and foraminifera; "banks" and "prairies" of animals as well as reefs are also mentioned. Classical notions regarding such deposits are retraced, both for recent sediments and the stratigraphic record.

Carbon also plays a significant role in biology and geology. After a discussion of the application of the principles of biology and chemistry to bogs, fossil peat-bogs and coal in the Carboniferous are considered.

Advancing thus little by little into the domain of life on the Earth's surface, H. and G. Termier are finally led to examine life's connections with great geologic phenomena. The story of the living world is irreversible, which provides each part of the great series of sedimentary strata with a proper personality.

Every age shows a close relationship between the general aspect of the Earth's surface and the distribution of vegetable and animal life. Thus the various marine transgressions have produced the great migrations.

On the basis of the geologic record, the notion of the permanence of continental areas and of the Pacific Ocean seems indisputable. On the other hand, two main

continental groupings appear in the evolution of the Earth: Gondwana and Laurasia.

With respect to Gondwana, the authors discuss both the older view that, during the Carboniferous and the Permian, a wide continental area existed joining South America to Africa, India, and Australia, and the hypothesis that continents essentially like those of the present-day were formerly bound by land bridges. By either theory, Gondwana was a craton or a shield stabilized long ago, a quite defensible view. On the other hand, the hypothesis postulating the existence of a single geographical continent embracing these different parts is, to say the least, extremely doubtful.

However this may be, the present authors must admit the sinking of continental masses in the course of geologic time. These vanished bridges have been called continental bridges. To abandon this opinion would make explanation of the faunal and floral uniformity of Gondwana difficult. Serious objections may be raised, however, and theories depend on the importance placed on these "bridges" or "isthmian links" (Bailey Willis' term).

The theory of continental drift does not convince the authors. They believe the strongest argument against it to be the periodic phenomena which have divided world history into geologic and sedimentary cycles. To be sure, they accept some drifting as well as some sinking of land bridges. They wisely rally to the opinion that the Pacific Ocean, Tethys, and the Arctic Ocean, are permanent. Geologists can surely agree with them.

The first part of the volume ends with a chapter dealing with the orogenic phases which express the Earth's pulsations. Their review of tectonic theories is quite short, for the aim of the work is primarily the consideration of all phenomena regarding life. In their conclusions, the authors say: "There is an undeniable relation between the activity of the areas of folding on the one hand, transgressions and regressions on the other." In their opinion, however, orogenic phases do not provide satisfactory criteria for stratigraphical correlation; they have only a regional value.

In the second part of the book, the authors set forth the successive geographies from Precambrian to our day. For the Precambrian, there is an almost unsurmountable difficulty—metamorphism; organic remains are rare and nearly always indeterminable.

The problems of the "Infracambrian" deserve special mention: glaciation, desert facies, lava flows. It is in rocks of that age that indisputable fossil remains first appear, notably the stromatolites that have greatly interested African geologists in recent years. It was at that time too that transgression started on Precambrian continents. The authors attempt to determine its cause. This attempt still seems a very dubious undertaking.

There follow a series of figures representing the paleogeography, biology, and geologic structure of 36 periods from the Infracambrian to the present. It would be impossible in this review to evaluate these figures. They are of indisputably great interest; if nothing else they give a schematic idea of what were the most striking features of the Earth's surface at each of these periods.

This review emphasizes the principles on which H. and G. Termier's work is based. In applying these principles, the authors attempt to sketch the geologic history of the Earth's surface from the Cambrian to the Pleistocene; to this they devote half their volume. In fact, this half is largely an explanation of the paleogeographic figures; in them, the geologist will find a mine of valuable information.

To conclude, the work of H. and G. Termier is remarkable in many respects; it gives, in an original form, the principles of the Earth Sciences, particularly as regards the evolution of life. The authors deserve congratulations for having

undertaken such a project. Let us add that the book, finely illustrated and well produced, is an honor to its editor.

P. FOURMARIER

LIEGE, BELGIUM,
November 24th, 1953

Man, Time and Fossils. By RUTH MOORE. Pp. 411; figs. 71; pls. 62. Alfred A. Knopf, New York, 1953. Price, $5.75.

It is unfortunate that *Man, Time and Fossils* is not quite as successful an attempt at presenting the informed lay public with a compact version of vast scientific data as was its predecessor, *Gods, Graves and Scholars*. Certainly, the publisher is to be congratulated for his very laudable idea of offering the general reading audience two books, and perhaps a series is intended, that contain actual scientific material prepared in such a way as to make it not only palatable but fascinating. However commendable the intention, the book itself leaves much to be desired. This reviewer has the feeling that Miss Moore was not as well equipped to handle her very difficult subject as she might be. It would seem that C. W. Ceram, the author of *Gods, Graves and Scholars*, is a more experienced amateur archeologist than Miss Moore is an amateur anthropologist. What is found to be lacking in Miss Moore's writing is the spark of true penetration into the subject. The tone of the whole book is that of a shallow, perfunctory examination, a newsreel, of one of the most complex and fascinating of all sciences—a tone perhaps better suited to an elementary high school text book. For it would appear that the book, although intended for a general audience, presupposes a certain already cultivated interest on the part of the reader, if not a somewhat informed reader. To such a reader, this book would offer little more in style and presentation than he is accustomed to finding in the science articles of his daily paper.

The value of the book is that it makes easily accessible, between the covers of a single volume, a tremendous quantity of material that is widely scattered, and that in its original form might not be of immediate interest to the lay reader. The book may also serve as a stimulus to less informed readers to go beyond this introduction into somewhat sturdier literature on the subject. To that purpose, this book has a carefully prepared bibliography, already selected, for the reader to choose from.

The edition is a handsome one filled with many line drawings and photographs. It is a pity, however, that there are not more photographs and fewer line drawings, for one might question the function and pertinence of many of the isolated flowers and animals. The book surely would have gained much by having more photographs accurately depicting samples that were collected by the various scientists themselves.

In spite of the apparent harshness of this review, *Man, Time and Fossils* will surely stimulate a great many readers and perhaps encourage a number of amateur scientists, and that is no small achievement.

B. A. BROMBERT

NEW HAVEN, CONN.,
December 20, 1953

General Chemistry. By LINUS PAULING. Pp. 722; pls. 2; figs. 193. 2nd Edition. W. H. Freeman and Company, San Francisco, 1953. Price, $6.00.

This volume by the outstanding authority on chemistry in this country is a second edition of his first book that appeared in 1947. A second book entitled *College Chemistry* appeared in 1950. At that time the author stated that he pro-

posed "in the near future, to revise *General Chemistry* in such a way as to make it especially suited to use by first year college students who plan to major in chemistry and by other well prepared students with a special interest in the subject." This present volume is the result. There are two new chapters dealing with atomic physics in which are discussed X-rays, radioactivity, the electron and nucleus and their properties, quantum theory, photoelectric effect, the photon, Bohr theory, and related aspects of atomic science. A chapter on biochemistry is also added, and the parts dealing with the chemistry of metals has undergone extensive revision. The remainder of the subject matter covered is generally similar to the predecessor volume, with, of course, revision throughout all of the chapters dealing with descriptive chemistry and theoretical subjects.

The book is nicely written in Professor Pauling's excellent style and well-chosen illustrations (mostly drawings) elucidate the text. It is an excellent second edition to an equally excellent first edition and should find a place as a college text book as well as an up-to-date reference for chemistry enthusiasts.

Materials Survey—Tin. Compiled for the National Security Resources Board by the U. S. Department of Commerce, National Production Authority. Pp. 769; illustrated. Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., 1953. Price, $4.25.

This thick volume is one of a series of volumes on strategic minerals initiated and arranged by the National Security Resources Board. Most of the volumes were prepared by the U. S. Bureau of Mines with the cooperation of the U. S. Geological Survey. Others were undertaken by the Department of Commerce. The present volume was contracted by the National Production Authority, which later came under the Office of Defense Mobilization, to the Pennsylvania State College, and the study was compiled by their Division of Mineral Economics under the direction of John D. Ridge, with considerable help from John J. Croston of the Defense Materials Procurement Administration.

The volume consists of 769 mimeographed pages with many diagrams, charts and tables divided into 20 sections. It is an extremely comprehensive study of the various phases of the tin industry. It covers properties, history, definitions, resources, mining, beneficiation, smelting, production, trade, uses, marketing, stocks, substitutes, companies, statistics, international control schemes and bibliography.

The volume as originally planned was to be a general reference available for the various agencies of Government to bring together all phases of the subject under one pair of covers, in order to guide government policies and programs relating to tin or to the producing countries. As now assembled, it is more than that. It should constitute a general reference for any organization, mining company, economist, or individual interested in any phase of tin.

The Composition and Origin of the Antrim Laterites and Bauxites. By V. A. Eyles. Pp. 90; pls. 2; tbls. 10. Memoir of the Geological Survey of Northern Ireland, Belfast, 1952. Price, 12s. 6d. net.

This volume covers more than the title implies, for it is a broad discussion of the whole subject of laterite and bauxite formation. It takes up the geologic occurrence of the Antrim laterites and bauxites, alteration processes, chemical changes involved, X-ray determination of the minerals, paragenesis, minor and rare elements, effects of heat on bauxite, and paragenesis of the oxide and hydrated oxides of aluminum. It is a book well worth reading for anyone interested in bauxite and laterite formation.

BOOKS RECEIVED

FRANK G. LESURE

U. S. Geological Survey—Washington, D. C., 1953.

Prof. Paper 250. American Triassic Coiled Nautiloids. BERNHARD KUMMEL. Pp. 104; pls. 19; figs. 43. Price, $1.25. *Study of classification and evolution of late Paleozoic and early Mesozoic Cephalopods; descriptions of new species.*

Prof. Paper 253. Geology and Larger Foraminifera of Saipan Island. W. STORRS COLE AND JOSIAH BRIDGE. Pp. 45; pls. 15; tbls. 5. *Preliminary report on geology and descriptions of some larger microfossils.*

Prof. Paper 243-D. Cenomanian Ammonite Fauna from the Mosby Sandstone of Central Montana. W. A. COBBAN. Pp. 45–54; pls. 7; fig. 1. Price, 55 cts.

Prof. Paper 243-F. Conodonts of the Barnett Formation of Texas. WILBERT H. HASS. Pp. 69–94; pls. 5; fig. 1; tbl. 1. Price, 55 cts.

Prof. Paper 243-H. Cranial Morphology of Some Oligocene Artiodactyla. FRANK C. WHITMORE, JR. Pp. 117–160; figs. 18. Price, 35 cts.

Bull. 987. Fluorspar Deposits of the Eagle Mountains, Trans-Pecos, Texas. ELLIOT GILLERMAN. Pp. 98; pls. 17; figs. 9; tbl. 1. *Includes general geology of area; detailed description of deposits.*

Bull. 989-C. Gypsiferous Deposits on Sheep Mountain, Alaska. RICHARD A. ECKHART. Pp. 39–60; pls. 2; figs. 6. *Description of six deposits.*

Bull. 992. Contributions to Geochemistry, 1949. W. W. BRANNOCK AND OTHERS. Pp. 94; pls. 14; figs. 17. Price, 65 cts. *Eight short papers dealing with new techniques and analytical methods including: determination of sodium and potassium in silicate rocks, estimation of oil yield of oil shale, determination of aluminum in phosphate rock, of phosphorus in rocks containing vanadium and of traces of silver in soils and rocks.*

Bull. 995-A. Constitution Diagrams of Pennsylvania Anthracite. HOLLY C. WAGNER. Pp. 18; pls. 7; figs. 3. Price, 65 cts. *Study of lithologic constituents of anthracite.*

Bull. 995-B. Quicksilver Deposits of Steens Mountain and Pueblo Mountains, Southeast Oregon. HOWELL WILLIAMS AND ROBERT R. COMPTON. Pp. 19–77; pls. 3; figs. 5. Price, 65 cts. *General geology and description of mines and prospects.*

Bull. 996-A. Pleistocene-Recent Boundary in the Rocky Mountain Region. CHARLES B. HUNT. Pp. 24. Price, 15 cts. *Stratigraphy and paleontology of alluvial, cave, and lake deposits of late Quaternary age.*

Bull. 998-B. Some Zinc-Lead Deposits of the Wrangell District, Alaska. H. R. GAULT, D. L. ROSSMAN, G. M. FLINT, JR., AND R. G. RAY. Pp. 15–58; pls. 10; figs. 4; tbls. 5. *Description of deposits at Groundhog Basin, Glacier Basin, Lake Claims, and Berg Basin.*

Bull. 1002-B. Geophysical Abstracts 153, April–June 1953. MARY C. RABBITT, S. T. VESSELOWSKY AND OTHERS. Pp. 63–121. Price, 25 cts. *Abstract numbers 14389–14598.*

Water-Supply Paper 1137-D. Floods of May–July 1950 in Southeastern Nebraska. Pp. 351–410; figs. 12; tbls. 3. Price, 25 cts.

Water-Supply Paper 1137-G. Floods of 1950 in the Upper Mississippi River and Lake Superior Basins in Minnesota. Pp. 791–893; pl. 1; figs. 12; tbls. 11. Price, 50 cts.

Geology of the Niota Quadrangle, Tennessee. JOHN RODGERS. *Includes stratigraphy and structure of area, and geologic map, scale 1: 24,000.*

Geology of the Athens Quadrangle, Tennessee. JOHN RODGERS. *Includes stratigraphy and structure of area, and geologic map, scale 1: 24,000.*

Circ. 290. Thorium Investigations 1950–52, Wet Mountains, Colorado. R. A. CHRISTMAN, A. M. HETMAN, L. F. DELLWIG, AND G. B. GOTT. Pp. 40; pls. 5; figs. 15; tbls. 10. *Description of prospects and logs of drill holes.*

Circ. 297. Progress Report on Investigations of Western Phosphate Deposits. R. W. SWANSON, V. E. MCKELVEY, AND R. P. SHELDON. Pp. 16; pl. 1; figs. 11. *Summary of scope of investigations and preliminary conclusions.*

Circ. 300. Reconnaissance for Radioactive Deposits in the Darby Mountains, Seward Peninsula, Alaska, 1948. WALTER S. WEST. Pp. 7; pl. 1; tbls. 2.

Circ. 301. Stratigraphic Sections of the Phosphoria Formation in Idaho, 1947–48, Part 2. V. E. MCKELVEY, F. C. ARMSTRONG, R. A. GULLBRANDSEN, AND R. M. CAMPBELL. Pp. 58; figs. 2.

Circ. 302. Stratigraphic Sections of the Phosphoria Formation in Montana, 1949–50, Part 1. E. R. CRESSMAN, W. H. WILSON, C. W. TANDY, AND W. J. GARMOE. Pp. 23; figs. 2.

Circ. 303. Stratigraphic Sections of the Phosphoria Formation in Montana, 1949–50, Part 2. R. W. SWANSON, E. R. VRESSMAN, R. S. JONES, AND B. K. REPLOGLE. Pp. 21; figs. 2.

Circ. 304. Stratigraphic Sections of the Phosphoria Formation in Idaho, 1949, Part 1. R. P. SHELDON, M. A. WARNER, M. E. THOMPSON, AND H. W. PIERCE. Pp. 30; figs. 2.

Circ. 306. Stratigraphic Sections of the Phosphoria Formation in Utah, 1949–51. T. M. CHENEY, R. A. SMART, R. G. WARING, AND M. A. WARNER. Pp. 40; figs. 2.

Circ. 307. Stratigraphic Sections of the Phosphoria Formation in Wyoming, 1949–50. R. P. SHELDON, R. G. WARING, M. A. WARNER, AND R. A. SMART. Pp. 45; figs. 2.

U. S. Atomic Energy Commission—Oak Ridge, Tennessee, 1953.

NYO-6199. Studies on the Lead Method of Age Determination, Part 1. J. LAWRENCE KULP, W. R. ECKELMANN, H. R. OWEN, AND G. L. BATE. Pp. 19. *Ages of a number of radioactive minerals determined from different lead isotope ratios.*

RME-3050. Fracture Pattern of the Zuni Uplift (Final Report). ARTHUR K. GILKEY. Pp. 34; figs. 8.

RME-3056. Annual Report from August 1, 1952 to July 31, 1953. M. R. MICKEY. Pp. 14.

RME-4-25. Routine Testing of Samples for Radioactivity in Mills and Assay Offices in the United States, A Progress Report. MURIEL NATHEZ. Pp. 6; figs. 2.

RME-4026. Preliminary Report on Uranium-Bearing Deposits in Mohave County, Arizona. OLIN M. HART AND D. L. HETLAND. Pp. 48; figs. 9.

RME-4-32. Preliminary Drilling at the Nash Car Area, White Canyon District, San Juan County, Utah. PAUL C. DEVERGIE. Pp. 13; figs. 4.

U. S. Department of Agriculture—Washington, D. C., 1953.

The Silting of Caonillas Reservoir, Puerto Rico. JOHN J. NOLL. Pp. 22; figs. 14; tbls. 9.

Sedimentation Bull. 5. Summary of Reservoir Sedimentation Surveys for the United States through 1950. Pp. 31.

California Division of Mines—San Francisco, 1953.

Special Rept. 34. Geology of the Santa Rosa Lead Mine, Inyo County, California. EDWARD M. MACKEVETT. Pp. 9; pls. 2; figs. 2. Price, 50 cts.

Special Rept. 37. Rosamond Uranium Prospect, Kern County, California. GEORGE W. WALKER. Pp. 8; figs. 5. Price, 25 cts.

Geology of the Thomasville–Woods Lake Area, Eagle and Pitkin Counties, Colorado. IAN H. MACKAY. Pp. 76; pls. 5; figs. 36. Quarterly of the Colorado School of Mines, Vol. 48, No. 4, Golden, 1953. Price, $1.00. *Detailed account of stratigraphy and structure of area.*

Illinois Geological Survey—Urbana, 1953.

Rept. of Inv. 162. Geologic Aspects of Radio Wave Transmission. M. WILLIAM PULLEN. Pp. 73; figs. 69. *Report on experiments designed to illustrate factors and features affecting radio field intensity. Includes theoretical concepts, description of equipment used, and effects of cultural and geological features.*

Rept. of Inv. 165. Pleistocene Deposits Below the Wisconsin Drift in Northeastern Illinois. LELAND HORNBERG. Pp. 61; pls. 2; figs. 16; tbl. 1. *Description and correlation of Pleistocene deposits.*

Petroleum 69. Oil and Gas Development in Illinois during 1952. ALFRED H. BELL AND VIRGINIA KLINE. Pp. 52; figs. 3; tbls. 7.

Circ. 185. Summary of Water Flood Operations in Illinois Oil Pools during 1952. PAUL A. WITHERSPOON AND OTHERS. Pp. 23; figs. 5.

Kansas University and Geological Survey—Lawrence, 1953.

Bull. 101. Geology and Ground-Water Resources of Jackson County, Kansas. KENNETH L. WALTERS. Pp. 90; pls. 10; figs. 9; tbls. 10.

Bull. 105. Geology and Ground-Water Resources of Sherman County, Kansas. GLENN C. PRESCOTT, JR. Pp. 130; pls. 11; figs. 12; tbls. 10.

Bull. 102, Pt. 3. Composition of Some Uranium-Bearing Phosphate Nodules from Kansas Shales. RUSSELL T. RUNNELS, JOHN A. SCHLEICHER, AND H. S. VAN NORTWICK. Pp. 93–104; figs. 3; tbls. 3.

Bull. 102, Pts. 4 and 5. Experimental Separation of Iron-Bearing Minerals from Certain Kansas Clays. FRANK W. BOWDISH. **Electron Microscopy of Fired Glaze Surfaces.** ADA SWINEFORD AND NORMAN PLUMMER. Pp. 105–124; pls. 4; tbl. 1.

Bull. 102, Pt. 6. Experiments in the Rapid Drying of Plastic Clay Brick. NORMAN PLUMMER AND WILLIAM B. HLADIK. Pp. 125–144; figs. 10.

Bull. 102, Pt. 7. Improvement of Some Kansas Clays Through the Control of pH and of Soluble Sulfates. NORMAN PLUMMER AND WILLIAM B. HLADIK. Pp. 145–173; figs. 8; tbls. 7.

Oil and Gas Inv. 10. The Petroleum Industry in Kansas. EDWIN D. GOEBEL. Map, scale 1 inch = 9.5 miles. *Includes oil and gas pipe lines, pools and refineries.*

New Hampshire State Planning and Development Commission—Concord, 1953.

Clay Deposits of Southeastern New Hampshire. LAWRENCE GOLDTHWAIT. Pp. 14; pl. 1; fig. 1.

Geology of the Sunapee Quadrangle. CARLETON A. CHAPMAN. Pp. 32; pl. 1; figs. 16. *Popularized account of geology of area.*

The Geology of the Wolfeboro Quadrangle. ALONZO QUINN. Pp. 24; pl. 1; figs. 9. *Popularized account of geology of area.*

Slagging of Navy Boiler Refractories. WILLIAM C. BELL, JOHN R. HART, AND IRVING W. GOWER. Pp. 46; figs. 52; tbls. 8. Department of Engineering Research Bull., North Carolina State College, Raleigh, 1953. Price, $1.00. *Description of simulated service test for evaluation of resistance of naval boiler refractories to sodium sulfate slag attack.*

Investigation of Some North Dakota Clays and Shales. OSCAR E. MANZ. Pp. 36; figs. 2; tbls. 4. North Dakota Geological Survey Rept. of Inv. 13, Grand Forks, 1953. *Preliminary investigation of use of North Dakota clays and shales in ceramic industries.*

Ohio Geological Survey—Columbus, 1953.

Oil and Gas Fields of Ohio. ROBERT L. ALKIRE. Revised edition, 1953. 41 in. × 53 in., scale, 1 inch = 6 miles. Price, $1.00 for folded map; rolled, 35 cts. additional. *Map shows names and locations of 832 oil and gas fields in Ohio; discovery date, producing sand, and average depth for each field.*

Lake Erie Pollution Survey. Final Report. Pp. 201; pls. 60; tbls. 89. *Contains chapters on hydrology, bacterial and sanitary analysis, and chemical and physical quality examination of Lake Erie and tributaries.*

Bull. 51. Mississippian Formations of Central and Southern Ohio. JESSE E. HYDE. Pp. 355; pls. 54; figs. 19.

Annual Coal and Non-Metallic Mineral Report, with Directories of Reporting Firms for 1952. Pp. 182. Ohio Department of Industrial Relations, Columbus, 1953. *Statistical data on coal and non-metallic minerals; contains minerals industry map, scale 1 inch to 8 miles.*

Fusulinids of the Casper Formation of Wyoming. Pt. 1, Stratigraphy of the Casper Formation. HORACE D. THOMAS, M. L. THOMPSON AND JOHN W. HARRISON. **Pt. 2, Systematic Paleontology of Fusulinids from the Casper**

Formation. M. L. THOMPSON AND HORACE D. THOMAS. Pp. 56; pls. 9; figs. 4; tbls. 4.

The Literature of Geology. COMPILED BY BRIAN MASON. Pp. 155. American Museum of Natural History, New York 24, N. Y., 1953. Price, $2.00. *Compilation of serial publications and significant literature on geology of individual countries in all parts of the world; copies obtained from author, Am. Mus. of Nat. History, New York 24, N. Y.*

Lineation, Review of Literature, 1942–1953. ERNST CLOOS. Pp. 14. Geol. Soc. of America, Supp. to Mem. 18, 1953.

Geological Society of America and Geological Ass'n of Canada—Toronto, 1953.

Guide Book for Field Trip No. 1. Petrology of the Nepheline and Corundum Rocks, Bancroft Area, Eastern Ontario. D. F. HEWETT. Pp. 28; figs. 13. Price, $1.00. *Includes brief description, road log, and 3 geologic maps.*

Guide Book for Field Trip No. 2. Mineral Occurrences of Wilberforce, Bancroft and Cragmont–Lake Clear Areas, Southeastern Ontario. V. B. MEEN AND D. H. GORMAN. Pp. 23. Price, $1.00. *Description of mineral occurrences, includes geologic maps of each area.*

Guide Book for Field Trip No. 8. Geology and Mineral Deposits of the Kirkland–Larder Mining District, Ontario. W. S. SAVAGE. Pp. 16. Price, $1.00. *General geology and structure; geologic map of area, 1 inch equals 2 miles.*

Guide Book for Field Trip No. 9. The Porcupine Mining District, Ontario. W. A. JONES. Pp. 31; figs. 4. Price, $1.00. *General geology and description of ore deposits.*

Guide Book for Field Trip No. 10. Geology and Mineral Deposits of Northwestern Quebec. J. E. GILBERT. Pp. 29. Price, $1.50. *Description of mines; 9 mine plans, 2 sections and geologic map.*

Present Needs for Research on the Use and Care of Natural Resources. Pp. 35. National Academy of Sciences, Publ. 288, Washington, D. C., 1953. Price, 50 cts. *Series of 15 papers presented in New York, November 1952, including discussion of forest, wildlife, water, soil and mineral conservation.*

Ontario Department of Mines—Toronto, 1953.

Bull. 25. List of Publications. Pp. 60. *Includes complete listing of reports, maps, and bulletins revised to October, 1953.*

Industrial Mineral Circ. 1. Asbestos in Ontario. D. F. HEWETT AND J. SATTERLY. Pp. 23; figs. 5; tbls. 6.

Map No. 1953-A. Mineral Map of the Province of Ontario. Scale 1 inch to 20 miles.

Fifth Empire Mining and Metallurgical Congress, Australia and New Zealand —Melbourne, 1953.

Handbook, Australia and New Zealand. EDITED BY MALCOLM GLEN. Pp. 255; illustrated. *Brief description of geography, climate, geology and history of mining development in Australia and New Zealand.*

Publ. Vol. II. Mining Methods in Australia and Adjacent Territories. EDITED BY R. PITMAN HOOPER AND A. B. BLACK. Pp. 374; figs. 79. *Descriptive information on practices of open mining, dredging, sluicing and underground mining in Australia, New Guinea and Fijii.*

Publ. Vol. III. Ore Dressing Methods in Australia and Adjacent Territories. EDITED BY H. H. DUNKIN. Pp. 317; figs. 52. *Covers principal metal ores and some non-metallic ores.*

Publ. Vol. IVa. Extractive Metallurgy in Australia, Ferrous Metallurgy. EDITED BY J. C. RICHARDS. Pp. 217; illustrated. *Includes chapters on metallurgical coke making, blast furnaces, steel making, iron and steel foundry, steel rolling mill, heavy forging and ferro-alloy practices.*

Publ. Vol. IVb. Extractive Metallurgy in Australia, Non-Ferrous Metallurgy. EDITED BY FRANK A. GREEN. Pp. 272; illustrated. *Includes chapters on the metallurgy of lead-silver, zinc, copper, cadmium, antimony, and aluminum; production of sulfur and refractories.*

Publ. Vol. V. Australian Mining and Metallurgy, Miscellaneous Features and Practices. EDITED BY A. W. NORRIE. Pp. 253; figs. 36. *Descriptions of ventilation, hygiene, safety, legislation, industrial procedures, education and training, and research in Australian mining and metallurgical industries.*

Publ. Vol. VI. Coal in Australia. Pp. 832; figs. 171. *26 papers including ones on geology of various coal deposits, discussion of physical and chemical characters of some coals, and accounts of the development, preparation and production of Australian coal.*

Bureau of Mineral Resources, Geology and Geophysics—Melbourne, 1953.

The Australian Mineral Industry 1952 Review. Pp. 210. Price, 12/–. *Includes statistics on Australian production, imports-exports, world production and value.*

Instituto de Pesquisas Radioativas, Universidade de Minas Gerais—Belo Horizonte, 1953.

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SOCIETY OF ECONOMIC GEOLOGISTS

Abstracts of Papers to be Presented at the Joint Meeting of the Society of Economic Geologists and the American Institute of Mining and Metallurgical Engineers, New York Meeting, February 15–18, 1954

THE OCCURRENCE OF MINERAL DEPOSITS IN THE PEGMATITES OF THE KARIBIB–OMARURU AND ORANGE RIVER AREAS OF SOUTH WEST AFRICA

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Pegmatites of the Karibib-Omaruru area and the area north of the Orange River, both in South West Africa, have become important sources of beryl and lepidolite, and have yielded cassiterite and columbite-tantalite. Prospecting and mining have been particularly active since World War II.

The pegmatites occur in pre-Cambrian metamorphic rocks that have been invaded by granites and other igneous rocks. The pegmatites show a wide variety of mineralogical composition. Most consist entirely or almost entirely of feldspar and quartz with or without micas, but some contain economic concentrations of beryl, lithium minerals, cassiterite, or columbite-tantalite, or combinations of these minerals. A variety of other minerals has also been reported.

Previous investigators have emphasized the role of replacement in the formation of the pegmatites, and have regarded the development of concentrations of beryl, lithium minerals, cassiterite, and columbite-tantalite as due to hydrothermal or pneumatolytic replacement of previously-formed quartz-feldspar pegmatites. A brief examination of the two areas indicates that although this conclusion is valid for some and perhaps the majority of the cassiterite deposits, it does not hold for deposits of the other minerals. In certain pegmatites cassiterite is found in replacement bodies formed at the expense of parts of distinctly to indistinctly zoned pegmatites. The mineral occurs in banded greisens that cut across zonal structures. All deposits of lithium minerals, beryl, and columbite-tantalite seen by the writer, however, are zones or parts of zones that have structural and sequential relationships similar to those described from zoned pegmatites in North America and elsewhere during the past 15 years. It therefore seems evident that present knowledge of the occurrence of minerals in zoned pegmatites can be applied to prospecting and mining of pegmatite deposits in these two areas of South West Africa.

LATERITIC NICKEL–COBALT DEPOSIT AT MOA, ORIENTE, CUBA

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The recently developed deposit of nickel-cobalt bearing lateritic ore at Moa, Oriente, Cuba, belonging to the Freeport Sulphur Co., is described. The ore is developed *in situ* by the weathering of serpentinized peridotites, and averages 22 feet

in thickness, with an average thickness of 15 feet of overburden. Ore reserves and average grades of nickel, cobalt and iron are stated, with an analysis of methods used in calculating reserves, particularly the determination of average moisture contents for the various ore intercepts, which vary from 15.1% at the top of the ore section to 53.5% in the lower portion, and average 36.6%. A method of correction for overstatement of nickel and cobalt grade because of varying moisture contents is described. Although the lateritic deposits are extensive, only a relatively small portion is found to have commercial nickel-cobalt values, and the use of aerial photographs and determination of variations in vegetation and soil types are of great assistance in reconnaissance. Hand augering, test pitting, churn drilling and machine augering methods were used, and it was found that hand augering during reconnaissance, followed by machine auger drilling on 100 meter centers in areas of interest, gave the best development pattern.

Physical and chemical characteristics of the various ore types are described, notably the color changes, variations in pore space and specific gravity, and chemical and mineralogical composition. Results of screening tests and sedimentation tests show 85.7% of the ore to pass 400 mesh, and the average grain size calculated arithmetically is 3 microns.

PROGRESS REPORT ON THE ORIGIN OF URANIUM DEPOSITS

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Continuing extensive geologic studies of uranium deposits all over the world increasingly demonstrate remarkable variety in the known types of economic concentrations of the element and the geologic and geochemical environments in which they are found. As new ore bodies are found and studied the necessary function of synthesizing their characteristics in all categories continues, in the attempt to find out with an adequate degree of certainty why uranium is where it is. One of the paramount questions in this regard is the ultimate origin of the deposits, which is commonly the key to the distribution of ore bodies within a metallogenic province.

The observed variety in types of deposits implies also a variety of processes by which deposits may originate and become emplaced, and yet the known basic geochemistry and physical behavior of uranium-bearing solutions must be reflected in any valid ideas of origin. We can now report specific progress in our understanding of the geochemical behavior of uranium in igneous intrusives, the nature of uraniferous hydrothermal solutions, the capabilities of cold aqueous solutions in the transportation and deposition of uranium, the nature of effective natural precipitants of uranium, and the behavior of uranium in detrital sediments. From these facts it is possible to advance reasonable working hypotheses for the origin of uranium in hydrothermal veins, pegmatites, disseminated deposits in igneous rocks, deposits in bedded terrestrial sediments, and in certain kinds of carbonaceous matter.

EDITH RIVER URANIUM DEPOSITS

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In the Edith River area uranium occurs mainly as meta-autunite associated with apatite and hematite in narrow siliceous reef formations which are in part brecciated and mylonized. In the principal area of mineralization, the reefs which dip steeply west and strike mostly north-northwest, occur over a length of about 3 miles in a north-south sheared, greisenized zone in granite. Other similar deposits have been found 3 to 4 miles west, and another group 2 to 5 miles north, which included the Yenberrie deposit. In this latter deposits the lode material consists of brecciated greisen and quartz veined with limonite, and torbenite is present in places.

Two main types of granite are present, a coarse-grained granite and a finer-grained adamellite, which appears to be intrusive into the coarse granite. In places partial digestion of the coarse by the finer granite has produced a porphyritic "hybrid" granite. All granites except the greisenized granite of the sheared zone give high background counts, 2 or 3 times as high as that of the Pre-Cambrian sediments of the Brocks Creek group into which the granites are intrusive.

Within the reef formations the distribution of uranium-bearing material is patchy. In many places the best geiger readings are obtained where cross reefs or fractures with a northeasterly strike meet the main reefs. Although the deposits are numerous, those found so far are individually too small and the grade too low for economical working.

The deposits in the main mineralized zone and the Yenberrie deposit were found by a syndicate consisting of Messrs. Young, Mazlin, Cousin and Atkinson, and those west of the railway line mainly by Mr. S. Tennyson.

URANIUM EXPLORATION, RUM JUNGLE PROVINCE, AUSTRALIA

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The Rum Jungle uranium province (more correctly referred to as the Katherine-Darwin area) extends between latitudes 12° 40′ and 14° 18′ S and longitudes 130° 35′ and 132° 30′ E.

Within this province, uranium occurs as replacement deposits, in places with copper and lead, in Pre-Cambrian sediments. Lesser deposits, in which uranium is associated with quartz and hematite are found in shears in granite. Small copper-cobalt-uranium deposits have also been found in or near granite.

Regional prospecting, based on air-photo geological mapping and air-borne scintillometer survey, is being systematically extended through the region, and may take 3 to 5 years to complete. As in Rhodesia and the Congo, particular formations are being found to be favorable for ore, and more detailed investigation of these formations is taking place.

A private company, Territory Enterprises Ltd., is developing and mining deposits at Rum Jungle itself and other companies and syndicates are beginning to be active elsewhere in the district.

Tropical weathering of outcrops combined with soil and laterite cover complicate interpretation of surface radioactivity, and bulldozers are widely used to obtain good exposures; diamond drilling is the usual method for preliminary testing of the sulphide zone, which lies at depths ranging between 30 and 200 feet.

DEVELOPMENT OF MONAZITE EXPLORATION TECHNIQUES

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In 1948, the U. S. Bureau of Mines contracted with the U. S. Atomic Energy Commission to undertake the evaluation of monazite placer deposits in the United States. It was necessary to develop new exploration, evaluation, and analytical procedures. Standard techniques employed in the sampling of gold placer deposits were found to be unsatisfactory for monazite deposits. Methods were developed for a rapid evaluation of the more promising deposits, and these were then systematically sampled by modified churn-drilling techniques. Gravity-concentration field laboratories were established and methods developed for the rapid field estimate of minerals contained in the black sands. For the final analyses of the concentrates a triple-check assay procedure employing petrographic, chemical, and radiometric methods was developed.

As a result of the above investigations, three dredges were put in operation in one area in Idaho and a dredging operation is planned on a deposit in South Carolina. As evidence of the accuracy of the evaluation procedures and techniques developed by the Bureau, the monazite content of the ground being dredged has proved to be comparable to that predicted. For the first time in the history of the United States, the rare-earth industry is not entirely dependent upon foreign sources of supply.

GENERAL STRUCTURAL RELATIONS OF THE UPPER MISSISSIPPI VALLEY ZINC-LEAD DISTRICT

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The Upper Mississippi Valley zinc-lead district lies 100 miles south of the southern edge of the Pre-Cambrian shield of North America. The Wisconsin arch lies to the east of the district, the Illinois basin to the south, and the Forest City basin to the west and southwest in Iowa. Practically all of the larger geologic structures observed in the Upper Mississippi Valley district, and nearby areas, appear to be the result of a period of major tectonic deformation, which was preceded by an earlier minor period of deformation and was followed by tilting and uplift.

The folds of the district are low broad asymmetrical undulations that trend northeasterly, easterly, or northwesterly—forming an unusual rhombic pattern—with the steeper dip commonly on the north limbs. Associated with the folds are the zinc ore bodies.

Most other structures in the district fall into well-defined interrelated patterns. The faults are reverse, bedding-plane, normal, or shear; most are small having displacements from 1 to 10 feet. Some thrusts on the steeper north limbs of the larger folds have displacements of 25 to 50 feet, and a few shear faults with displacements of from 25 to possibly 1,000 feet have been located. All the rock formations contain well-developed vertical and inclined joints. In general, the vertical joints can be grouped into three trends, N 77° W, N 13° W, and N 25° E. Many joints of the first and second trends contain lead deposits.

STRUCTURAL AND STRATIGRAPHIC CONTROL OF ORE DEPOSITION IN THE SHASTA COPPER-ZINC DISTRICT, CALIFORNIA

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The base metal ore bodies in the western part of the Shasta copper-zinc district of northern California are thick, flat-lying lenses of massive pyrite that contain chalcopyrite and sphalerite. Ore bodies are elongated parallel to folds along the crest of a broad, gently plunging anticlinorium and are confined to the soda-rich Balaklala rhyolite of Middle Devonian age. The rhyolite has the form of a complex elongate volcanic pile that contains many flows and beds of pyroclastic material. It has been subdivided into three stratigraphic units, and the ore bodies are replacements of flows and pyroclastics in the upper part of the middle stratigraphic unit. During folding, bedding-plane movement and resulting foliation were concentrated in layers of pyroclastics in this zone. Steep fracture cleavage developed along folds in the lower and middle units of the Balaklala but did not develop in the massive upper unit. The zones of fracture cleavage, and a few feeder fissures, acted as collecting channelways for rising ore-bearing solutions. The solutions were then channeled through the rocks below the gently dipping base of the massive upper unit by bedding and by bedding-plane foliation in the rhyolitic flows and pyroclastics.

PRODUCTIVE ORE DEPOSITS OF THE METALINE DISTRICT

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The Metaline District includes about three hundred square miles in the northeast corner of Washington and can be described as the Pend Oreille river watershed from Ione, Washington, north to the International Border. Not included is the important zinc and lead area between Salmo, British Columbia, and the border.

Important production to date has been predominantly lead and zinc and mainly derived from a zone from fifty to one hundred fifty feet below the top of the Metaline limestone. The only comparatively dependable formational markers are the major depositional contacts such as that between the Metaline limestone and the overlying Ledbetter slate. Differences in lithological detail due to deposition are subordinate to differences due to silicification, dolomitization, and other expressions of metamorphism of moderately low temperature but accompanied by considerable stress. Reasons for a specific horizon being favorable to ore deposition are sometimes apparent but more often subject to a wide range of speculation.

The ores are of Tertiary—probably Miocene—age and are subsequent to and connected with the intrusion of the Kaniksu batholith. Introduced mineralization products were first jasperoid, then sphalerite and galena with overlapping and with the galena depositing more erratically. Up flowing channelways of the mineralizing solutions were near-vertical faults and shear zones. The solutions dispersed along comparatively flat dipping thrust fault planes and deposited before reaching the overlying dam formed by the Ledbetter slate. Thus the three way intersection of near vertical shearing, low angle shearing, and the favorable horizon constitutes the preferential control for ore deposition.

THE FRIENDS STATION–NEW MARKET ZINC-BEARING AREA IN EAST TENNESSEE

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The Friends Station-New Market Area forms approximately the central third of the Mascot-Jefferson City mining district in Tennessee.

The Grasselli and North Friends Station mines are operating in the area and a third—the Young mine—is being developed.

The area is underlain by folded and faulted sedimentary rocks of Cambrian and Ordovician age, the distribution of which is shown on an accompanying geologic map. Table I gives the general features of the stratigraphic units and shows that the zinc mineralization occurs in the three upper formations of the Knox dolomite.

Recent prospecting in the area by the American Zinc Company discovered one of the largest ore bodies in the district, parts of which form, stratigraphically, the highest minable ore known locally. That exploration supplied material for the first detailed description of the formation in which it occurs—the Mascot (Table 2). The mineralization extends through a stratigraphic range of 672 feet and to nearly 2,500 feet below the surface.

The ore bodies are large and irregular. They are localized in fractured and brecciated beds of dolomite and limestone the latter of which frequently is altered to crystalline dolomite.

This area is believed to demonstrate a direct relationship between ore occurrence and regional geological structure. The ore bodies are in anticlines which have been overridden by an overthrust fault of considerable magnitude. The deformation caused intense shattering by bedding plane and tearing movements which contributed significantly to the formation of the ore reservoirs. Solution and alteration of the limestones may have caused foundering of the fractured dolomites and created voids into which large breccia blocks were moved by compression.

GEOLOGIC STRUCTURE AROUND THE SANTA RITA, NEW MEXICO, INTRUSIVE

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The Santa Rita intrusive is one of a half dozen or more masses of igneous rocks which are exposed invading Cretaceous sediments and volcanic rocks, and earlier sediments in an area roughly 300 square miles in southwestern New Mexico. This area is bounded on the northeast and southwest by strong fault systems while Tertiary volcanic rocks and Quaternary alluvium cover the sediments and therefore form the boundaries on the north and south.

The structure between these fault systems, some 16 miles apart, consists of a gentle northwesterly trending syncline, modified by considerable faulting, tilting of the formations and by superimposed anticlinal structures which appear to be related to the intrusive action of the igneous rocks.

The Santa Rita intrusive is an elongated body trending approximately 20° west of north, with an exposed length slightly in excess of 6,000 feet and a visible width at its narrowest point of about 2,000 feet. It appears to occupy the intersection of two strong fault systems, and lies along the axis and on the south plunging nose of a narrow anticlinal fold in the north end of which lies the Hanover intrusive.

CERTAIN STRUCTURAL FEATURES OF PORPHYRY COPPER DEPOSITS IN THE WESTERN AND SOUTH-WESTERN UNITED STATES

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General characteristics of the so-called porphyry copper deposits now known to occur in the western and southwestern United States are briefly reviewed before proceeding to a consideration of several related structural features that have aided in their localization.

It is pointed out that a concentration of these ore bodies, as well as of other types of deposits, is found outside of but relatively near the western and southwestern margins of the Colorado Plateau where intersections of nonpersistent structures occur abundantly, and certain of these intersections apparently served as channelways for the introduction of magma and mineralizing solutions.

In many of these porphyry copper deposits the host rock has been made permeable by several intersecting sets of close-spaced joints. These are held to be members of a regional fracture pattern that varies locally in the strength of its development and in the extent of its distribution.

Where the restricted channelway that introduced the metalizing solutions flared into the large receptacle prepared by these intersecting joints precipitation of primary ore or low-grade protore was effected.

STRUCTURAL CONTROL OF GLOBE–MIAMI DISTRICT, ARIZONA

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The mineral deposits of the Globe-Miami and Pioneer districts have produced copper and subordinate amounts of silver, gold, zinc, and lead valued at more than a billion dollars. They are confined within a northeast-trending zone about 6 miles

wide and 30 miles long. The individual deposits of the Globe-Miami district are all characterized and apparently controlled by northeast-trending structures. The mineral zone is further defined by the structures of the lower Precambrian basement rocks and by the elongation and alinement of many bodies of intrusive rocks that have no counterparts beyond the limits of the zone.

This zone of mineral deposits and igneous intrusions lies across the most prominent orogenic belt of the region; that is, the belt that extends diagonally across Arizona from the northwest to the southeast corner and forms the southwest segment of the peripheral zone of the Colorado Plateau.

The mineral deposits and the various igneous intrusions appear to have been localized at a place of structural weakness formed at the crossing of the two zones. The zone trending northeast probably developed during the early Proterozoic Mazatzal revolution of central Arizona; the other trending northwest was formed during the late Cretaceous or early Tertiary orogeny of the Rocky Mountain region. Toward the end of this later orogeny, the great disseminated copper deposits of the Miami area and the rich vein deposits of the Globe and Superior areas were formed.

STRUCTURE AND MINERALIZATION, SILVER BELL, ARIZONA

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Replacement-type ore bodies in tactite have accounted for the Silver Bell District's modest production of copper in the past. In the near future, substantial production will come from porphyry-type copper ores occurring in two deposits spaced two miles apart within a northwesterly-trending zone of hydrothermal alteration some seven miles in length. This zone lies along a major regional fault which is believed to have formed initially in Paleozoic and Cretaceous sedimentary rocks, and subsequently to have been the locus of repeated Laramide igneous activity. Alaskite was intruded first, followed by dacite porphyry. Then, after an erosional interval marked by basal conglomerate, a thick series of dacite flows and pyroclastics was deposited. Intrusions of small stocks of monzonite and related dikes were preceded and partly controlled by (1) regenerative movement along the main zone and (2) development of cross-breaking fractures. Renewed development of cross-breaking joint systems along the main zone provided the principal control of ensuing hypogene mineralization. Post-mineral andesite dikes were intruded parallel to the main zone. Lastly, enrichment by supergene chalcocite formed the two ore bodies.

Features considered significant: (1) The belt of alteration and copper mineralization coincides with the inferred position of the original, major fault. (2) The systems of close-spaced, parallel joints were most favorable to deposition of the primary chalcopyrite. (3) The intensity and extent of supergene enrichment are reflected by the quantity of limonite-after-chalcocite in outcrops. (4) The erosional interval between alaskite and monzonite may be a useful means in age-distinction of Cretaceous and Tertiary igneous rocks.

GEOLOGY OF THE COLD SPRING TUNGSTEN MINE, NEDERLAND, COLORADO

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The operator of the Cold Spring mine is conducting an extensive exploration program, with aid from the Defense Minerals Exploration Administration, at the

property situated in the west-central section of the Boulder County tungsten belt, thirty miles northwest of Denver, Colorado. The program, to December 1, 1953, has been successful in opening up some blind ore bodies in a blind vein between the third and sixth level horizons (175 to 330 feet below the surface), and also in indicating ore of commercial grade at a horizon 200 feet below the seventh or bottom level (665 feet below the surface).

Ferberite-bearing veins cross the property in a northeasterly direction in a host rock of medium to coarse, gray, gneissic quartz monzonite of Pre-Cambrian age. The veins dip steeply, usually to the northwest. Filling consists mainly of the following: cryptocrystalline gray quartz; cryptocrystalline to fine crystalline ferberite; seldom a little fine disseminated pyrite; and rarely galena. In the larger high-grade ore bodies crystalline ferberite and little or no quartz commonly occur as the matrix of brecciated country rock within fracture zones.

The dimensions of the largest recently discovered ore shoot do not exceed those of the largest previously mined ore shoots, but the grade of the newly discovered ore appears to be equal to, if not greater than, previously mined ore. The grade varies from 2% to 20% WO_3, and one small high-grade lens, recently extracted, averaged 40% WO_3. Production is currently running approximately 8.0% WO_3.

PRELIMINARY REPORT ON REPLACEMENT AND ROCK ALTERATION IN THE SOUDAN IRON ORE DEPOSIT, MINNESOTA

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It has long been recognized that the massive hematite ore of the Soudan Mine must have been largely formed by replacement. Evidence is the lack of any appreciable porosity or shrinkage from the original width of the jaspilite beds; also the bands of the original jaspilite can be seen passing into solid ore with the banding faintly preserved.

Although the evidence for replacement is conclusive, knowledge of the nature of the process of replacement has been largely lacking. Detailed studies of the wall rocks show that extensive chemical changes have gone on, doubtless coincident with the formation of the ore bodies.

Sericite schist is abundant in and near the Soudan ore bodies but largely lacking elsewhere. It is now believed that the sericite schist originated by hydrothermal alteration of the greenstone wall rock. The change involves a loss of iron, particularly ferrous iron, lime, magnesia and soda and a gain of potash, silica and in some samples of carbon dioxide.

The most noteworthy change, and one that is not at all evident in field examination, is the development near the ore of greenstone that consists largely of iron chlorite. Maximum total iron in greenstones analyzed thus far is 39 percent and maximum FeO is 26.3 percent as compared with an average of about 7.5 percent Fe in normal greenstone and the same amount of FeO.

Relations in the mine as brought out by openings, and unusually extensive diamond drilling, show that ferric iron (hematite ore) largely replaces quartzose jaspilite whereas ferrous iron replaces only greenstone as far as present evidence permits us to judge. The relation of the sericite schist and iron chlorite rock remains to be determined.

INVESTIGATIONS OF URANIUM-BEARING DEPOSITS OF THE BOULDER BATHOLITH, MONTANA

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The Boulder batholith of western Montana consists primarily of early Tertiary quartz-monzonite which encloses remnants of older volcanic rocks and is host to later dikes and extrusives. Dikes and irregular masses of aplite and alaskite are common in some areas, and uraniferous deposits are found intimately associated with these late differentiates in two general types of deposits. Small tonnages of uranium ore have been derived principally from so-called "siliceous reefs" occupying prominent shear zones that have been recurrently brecciated and silicified. Several base-metal type veins contain interesting quantities of uranium as evidenced by material on waste dumps of inaccessible mines although uranium ore has been produced from only one of these deposits.

Similar in many respects to uranium deposits in northern Portugal, the Montana occurrences are simple in mineralogy and have an abundance of gummite and other secondary minerals in the oxidized zone. Pitchblende has been noted in many of the deposits. Silver is of economic importance in at least one of the siliceous breccia deposits but uranium has been found to be of greater value than other metals in the uraniferous material of base-metal type veins.

Uranium, widely distributed though in small amounts is also found in the Butte district, and though not commercial in present showings, indicates that the entire batholith may be considered a uranium province.

HYDROTHERMAL ALTERATION AT THE CLIMAX MOLYBDENITE DEPOSIT, COLORADO

JOHN W. VANDERWILT AND ROBERT U. KING

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The rocks in the Climax molybdenite deposit are pre-Cambrian biotite-schists and biotite-muscovite granite intruded by Tertiary porphyritic rocks that range in composition from quartz monzonite to diorite.

Molybdenite deposition and related hydrothermal alteration extend over a circular area about a mile in diameter and is centered above, partly around, and within a mass of altered Tertiary porphyry which is believed to be the top of a stock. Exploration by means of mine development and diamond drilling has advanced to a depth of 3,000 feet below the outcrop. Molybdenite deposition with related hydrothermal alteration is continuous throughout the area explored and to an unknown depth.

Hydrothermal alteration is characterized by extensive quartz and feldspar replacement of each rock type. Sericite, clay minerals, topaz, and fluorite are common alteration minerals. The more abundant metallic minerals found throughout the area of mineralization are molybdenite and pyrite, with lesser amounts of hubnerite, cassiterite, monzonite, chalcopyrite, galena, and sphalerite, and traces of several accessory minerals.

The most intensive hydrothermal alteration, measured by quartz and orthoclase replacement, forms a cap and blankets the north and west flank of the porphyry stock. Alteration in general decreases gradationally from the areas of greatest quartz-orthoclase replacement and molybdenite deposition toward the margin of the mineralization area.

In places the primary quartz and feldspar and other minerals have been replaced by the same minerals with different textures. In places modified textures and mineral composition make identification of rock types difficult.

SCIENTIFIC NOTES AND NEWS

HARRY J. WOLF is examining mineral deposits and inspecting mining and milling operations in Brazil, where he will be engaged for several months. Before returning to New York, Mr. Wolf will visit Uruguay, Argentina, Chile and Peru.

GUNTHER F. JOKLIK, geologist, who was with the Bureau of Mineral Resources, Canberra, Australia, is now with the geology department at Columbia University in New York.

A. K. SNELGROVE, head of the department of geological engineering, Michigan College of Mining and Technology, has accepted a Fulbright award to lecture at the University of Hong Kong, 1953 to 1954.

DOUGLAS C. BROCKIE is now senior geologist with Tri-State mines, mining and smelting division, The Eagle-Picher Co., Cardin, Okla.

F. A. VENING-MEINESZ, professor of geodesy and geophysics at the Universities of Utrecht and Delft in the Netherlands, and R. ROELOFS, director of the Institute of Geodesy at the Technical University of Delft, participated in a series of lectures running from October 21 to December 6, under the sponsorship of the Institute of Geodesy, Photogrammetry and Cartography, and the Mapping and Charting Laboratory of the Ohio State University.

CARLTON D. HULIN, formerly head of the geology department of the University of California, has been appointed to the Board of Directors of Haile Mines, Inc. It was under his guidance, while a consultant to that company, that its subsidiary, Tungsten Mining Corp., was developed.

GEORGE A. KIERSCH has been appointed director of the mineral resources survey, Navajo-Hopi Indian Reservations, Arizona, for the University of Arizona, succeeding Prof. E. D. McKee who resigned to join the USGS at Denver, Colorado. Dr. Kiersch has been supervisor of the field operations since the start of the survey in June, 1952.

KEITH WHITING, former exploration engineer in American Smelting and Refining Co.'s Western Mining Department, has been placed in charge of the company's exploration office in Toronto, Canada.

ARTHUR B. VAN TINE has joined the staff of the Department of Geology at Rensselaer Polytechnic Institute, it was announced by Dr. Paul E. Hemke, dean of the faculty.

RALPH W. MARSDEN, Oliver Iron Mining Division geologist, has been promoted to manager of geological investigations of the company. Norman A. Moberg, assistant to the general mining engineer, has become manager of engineering.

WILLIAM E. WRATHER, director of USGS, and past president of AIME, has been awarded the John Fritz medal for notable scientific achievement by unanimous choice of the 16-man board.

R. B. GRAHAM, for the past ten years associated with the Quebec Department of Mines as geologist, has joined the staff of the Cyprus Exploration Corp., in Toronto.

ARNOLD S. BUNTE, of Roswell, N. M., has been appointed associate professor of geology at the Colorado School of Mines for the 1953–54 academic year.

DONALD H. MCLAUGHLIN, San Francisco, president of Homestake Mining Co., was elected chairman of the American Mining Congress, which held its annual meeting in Seattle, Wash., in September.

A. A. BAKER gave his presidential address December 9 before the Geological Society of Washington on "The Geologic Structure of the Wasatch Range near Provo, Utah."

EDWIN T. HODGE, retired professor of economic geology, Oregon State College, has just returned from a year's trip into Angola, West Africa for the Bethlehem Steel Company.

JOHN D. RIDGE, associate professor and chief of the Division of Mineral Resources at the Pennsylvania State College, has been named professor of mineral economics and assistant dean, School of Mineral Industries, in charge of resident instruction, effective October 16. Dr. Ridge will also continue as chief of the Division of Mineral Economics.

THE EIGHTH PAN PACIFIC SCIENCE CONGRESS was held in Manila, November 16–28. Two hundred and fifty foreign delegates from nineteen countries within, or contiguous to, the Pacific basin met in Manila. The Fourth Far Eastern Pre-History Congress which is held less frequently gathered concurrently with the Eighth Pan Pacific Science Congress. Among geologists attending the Congress were James Healy, Geological Survey of New Zealand; H. Brouwer of the Netherlands; Teiichi Kobayashi of Japan; Gordon MacDonald, Director of Hawaiian Volcano Observatory; Irene Crespin and J. Thompson of Australian Geological Survey; Sir Edward Bullard of Great Britain; Frederick Fitch, Geological Survey of North Borneo; M. Edmund Saurin, Viet Nam; Prof. Juan Vei-Chow, Taiwan; G. A. de Neve and Th. H. F. Klompe of Indonesia; Prof. S. G. Davis, University of Hongkong; Preston Cloud, Earl Irving, Charles Johnson, Joshua Tracey, J. Marvin Weller, of the U. S. Geological Survey; Prof. Edward Sampson of Princeton; Prof. K. O. Emery, University of Southern California; Robert Dietz, Naval Research Institute, San Diego; and Howell Williams, University of California. Several intra-session and post-session tours were held. The next Congress, the ninth, will be held in Bangkok, Thailand, probably in January, 1958.

The 1954 Annual Meetings of the AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, the SOCIETY OF EXPLORATION GEOPHYSICISTS, and the SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS will be held in Kiel Auditorium, St. Louis, Missouri, April 12–15. Special low-cost, dormitory-style hotel housing has been provided for students. Requests for these accommodations must be submitted on the "Application for Special Student Housing Accommodations" form. A copy of this form is available for each college or university department of geology or geophysics, on application to Dr. A. F. Fredrickson, Department of Geology, Washington University, St. Louis, Missouri.

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, ROCKY MOUNTAIN SECTION, will hold its Fourth Annual Meeting at Albuquerque, New Mexico, February 22, 23 and 24, 1954.

H. CAYFORD BURRELL died suddenly on November 9 in Pittsburgh, where he had gone on a business trip from his late home in San Francisco. Dr. Burrell was one of the men chiefly responsible for the discovery of the Cerro Bolivar iron deposit in Venezuela.

The A.I.M.E. announced the following officers of 1954: LEO F. REINARTZ, vice-president, Armco Steel Co., of Middletown, Ohio, as president; THEODORE BENTON COUNSELMAN, manager of FluoSolids sales for the Dorr Co., Stamford, Conn., and HAROLD DECKER, president of the Houston Oil Co. of Texas as vice-presidents. Directors elected for three-year terms are E. C. BABSON, manager of Canadian Division of Union Oil Co., Calgary, Alberta; GEORGE D. DUB, assistant to the president of Cyrpus Mines Corp., Los Angeles; RALPH E. KIRK, manager of Raw Materials, Tennessee Coal and Iron Division, U. S. Steel Corp., Fairfield, Ala.; CARLETON C. LONG, director of St. Joseph Lead Co. Plant Research, Monaca, Pa.; EARL ROBERT MARBLE, manager, Tacoma Washington Smelter, American Smelting and Refining Co.; and PHILIP J. SHENON, private geology consultant, Salt Lake City. H. DEWITT SMITH, vice-president of Newmont Mining Corp., 14 Wall Street, New York City, will also serve as director of the Institute for 1954. Mr. Smith has been designated president-elect for 1954 and will take office as president of the AIME in 1955.

CHARLES STEEN, chief geologist for the Utex Exploration Company, has been nominated by the Grand Junction, Colorado Junior Chamber of Commerce as one of the 10 outstanding young men in America. Mr. Steen prospected the Big Indian Canyon area near Moab, Utah and discovered rich uranium ore bodies.

SAMUEL KATZ, geophysicist at Stanford Research Institute, has won the 1953 George Frederick Kunz Prize in Geology and Mineralogy awarded by the New York Academy of Sciences for his paper on "Seismic Study of Crystal Structure in Pennsylvania and New York."

TRUMAN H. KUHN, professor of geology and Dean of the Graduate School at the Colorado School of Mines, recently returned from Turkey where he estimated the chromium reserves on a 36-square-mile area for a Turkish mining company, whose guest he had been.

ALBERTO J. TERRONES L. has been promoted to the capacity of assistant chief geologist in charge of exploration for the Cerro de Pasco Corp. in Lima, Peru.

THE EASTERN REGIONAL MEETING of the SOCIETY OF EXPLORATION GEOPHYSICISTS was held on December 29 in Boston at which 11 papers were read by some of the nation's top geophysicists.

AUSTIN E. JONES, geophysicist, USGS, formerly in Washington, D. C., is now in Unalaska, Alaska. Mr. Jones expects to be there for the winter.

J. A. CHRISTENSON, Pacific Western Oil Corp., is in Kuwait, Persian Gulf, as petroleum geologist and representative in Pacific's joint operation in the Kuwait-Saudi Arabia Neutral Zone.

The Secretary of the Interior has established a survey committee headed by J. R. VAN PELT, president of the Montana School of Mines, to investigate and analyze the organization and operation of the USGS and to render a report by December 15, 1953. Other members of the committee are SAMUEL G. LASKY, of the Interior Dept.'s technical review staff, JOHN C. FRYE, of the University of Kansas, WILLIAM B. HEROY, Beers & Heroy, Dallas, DONALD M. DAVIDSON, vice-president of E. J. Longyear Co., Minneapolis, and HORACE M. ALBRIGHT, president, U. S. Potash Co., Inc., New York.